AD-A175 898

VOLUME 18, NO. 11
NOVEMBER 1986

THE SHOCK AND VIBRATION DIGEST

A PUBLICATION OF
THE SHOCK AND VIBRATION INFORMATION CENTER
NAVAL RESEARCH LABORATORY
WASHINGTON, D.C.

JAN 13 1987

DTIC FILE COPY

OFFICE OF
THE UNDER
SECRETARY
OF DEFENSE
FOR RESEARCH
AND
ENGINEERING

Approved for public release; distribution unlimited.

SVIC NOTES

SO LONG AND THANKS

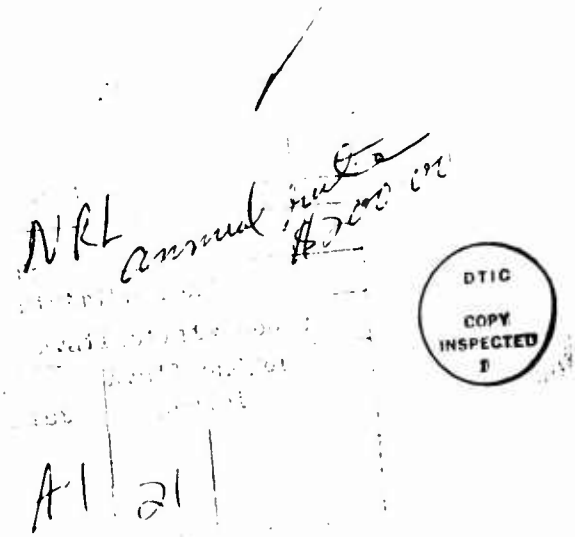
This will be the last time I will write this column so I wish to use this to personally thank all of you for helping us to perform our mission more effectively. Ideally it would be nice to thank each one individually, but this is not practical from the limitations of space and time. So the best I can do is to thank you collectively.

The Shock and Vibration technical community has been an open community, a cooperative community, and a sharing community. The members of this community have been more than willing to embrace newcomers, to share their knowledge, and to bring them up to speed rapidly. This open attitude is an important reason for the substantial progress that has been made over the past 40 years in understanding shock and vibration and in solving some of the thorny problems that arose, and in a timely fashion. I extend my thanks and my congratulations to the entire community for their openness and their spirit of cooperation. Without these, little progress would have been made.

Many examples of this cooperative spirit within the Shock and Vibration technical community could be cited. The willingness to contribute papers to the Shock and Vibration Symposia, the willingness to review papers for publication in the Shock and Vibration Bulletin, and the willingness to contribute feature articles, book reviews, and meeting reviews to the Shock and Vibration Digest are a few of the many examples. But, one of the most important examples has been the cordial reception we on the SVIC staff have received whenever we have visited the many organizations that comprise this technical community. These visits have been interesting, and they have always produced a wealth of information; they have also been very instrumental in helping us to perform our mission. Many thanks for this technical cooperation.

In closing, I would like to thank all of you for the splendid cooperation, and I wish you the best in your endeavors.

Rudy Volin



EDITORS RATTLE SPACE

THE ROLE OF SECONDARY JOURNALS IN RESEARCH, DESIGN, AND MAINTENANCE

Secondary journals like the DIGEST provide a distillation and organization of the published literature. These journals provide engineers involved in research, design, and maintenance an overview of the literature in a minimum amount of time. Instead of scanning several hundred journals and report listings, which would involve days of effort each month, the engineer need only spend a small amount of time with a secondary journal to achieve the same result. Thus the task of scanning the literature has been greatly reduced by distillation and organization. The remainder of the time can be spent more wisely in the review of new technical material or tutorials.

Why scan the new published literature? Despite the amount of repetitive and insignificant literature published, there is always a hard core of excellent new material in journals and reports. It is the type of material that will eliminate reinventing the wheel and save time and money on engineering costs. In essence, more accomplishments will be achieved for the time and money expended. It is my firm belief that most engineers could save up to fifty percent of the cost of technically oriented work if they had a thorough awareness of the technology available for the taking. Most engineers do use handbooks to ease the burden of everyday run of the mill tasks. Use of the new literature is just an extension of the handbook concept. Handbooks are good as far as they go but it takes years to distill this technology and data. Therefore, by the nature of their difficulty to organize and write, they are three to five years out of date.

Research, design, and maintenance engineers, in their own way, can all benefit from the use of newly developed technology. For the researcher the secondary journal provides the survey of the literature needed to establish a technology base upon which the research effort is built. The survey can ensure that only necessary research is performed. The secondary journal provides the initial survey from which the researcher can concentrate in-depth in a narrow area of the problem. The designer can benefit from new data, concepts, and techniques offered by others. It has been shown that, through the use of current vibration technology, predictive maintenance practices can save millions of dollars per year and relieve the anxiety of production engineers in controlling operating machinery.

We live in an era where engineers are eager to share their ideas and data with others. In fact, they use their own time to organize and document their work. It is senseless not to take advantage of their efforts and reduce the time and effort required to perform technically oriented engineering tasks. The secondary journal is the mechanism for cost effective utilization of current technology.

R.L.E.

IMPACT STRENGTH OF CONCRETE

M.A.G. Silva* and D. Krajcinovic**

Abstract. This review focuses on some of the unresolved and controversial aspects of the impact strength and dynamic fatigue of concrete. The authors suggest that continuum damage mechanics is the most appropriate framework for the development of a rational theory for predicting the impact strength of concrete. Unfortunately, perusal of the published literature indicates that such a model has not yet been developed.

Dynamic fracture of materials is an ill-defined term applied to a group of diverse problems with little in common. It refers to a range of problems from the propagation of a single, geometrically well-defined crack to spalling, scabbing, impact fatigue, fragmentation, and projectile penetrations. These phenomena involve radically different changes in material structure before ultimate failure occurs. It would therefore be unrealistic to expect that it is possible to have a single, relatively simple, and yet sufficiently accurate analytical model to deal with all of these phenomena. In fact, because of the complexities involved, a particular model is satisfactory if it is usable as a predictive tool within the limitations of a set of physical parameters that characterize a particular phenomenon.

This discussion is limited to the low velocity regime of impact speed (less than 250 meters/sec) that is of primary interest in nonmilitary applications of concrete [34]. The high and very high velocity regime, in which such local behavior as pulverization is a dominant factor, are not included. The focus is on concrete -- and by inference on other brittle materials such as unconfined rocks, bones, brittle irons, ceramics, and glasses. The cleavage I [2] mode of microstructural changes is stressed. The objective of this paper is thus to describe the impact strength of defect-sensitive materials.

The nonlinearity of the mechanical response of such materials reflects the existence of an ensemble of small crack-like defects distributed in a reasonably homogeneous fashion over large parts of materials. Many comprehensive reports, summaries, and state-of-the-art reviews are available [1,8,15,21,29]. This article points out certain aspects that have not received attention in previous work. The arguments are from the point of view of an analyst with the objective of predicting the behavior of a structure.

MICROMECHANICAL ASPECTS OF DEFORMATION

Concrete is a complex composite material [32]. For the stress analyst concrete consists of aggregate (hard inclusions) embedded into cement paste (weaker matrix). Concrete contains a large number of small defects even before a load is applied. These initial defects are attributable to bleeding, shrinkage, cement hydration, and heat. Proper attention to the composition of the mixture and casting can diminish these defects, but they cannot be avoided totally.

It is known that nonlinear mechanical response and ultimately the failure of concrete is related to these small defects; their distribution, density, orientation, and kinetics are important. In general, failure of a solid in a brittle mode reflects a micromechanical process consisting of three phases: nucleation of microdefects, their evolution, and ultimately their localization into a macrocrack at incipient failure [7]. In the case of concrete and other defect-sensitive materials the first phase is absent because the defects are present in the material before loads are applied.

The evolution of initially existing defects in concrete depends on the state of stress -- specifically, on the relative orientation of defects with respect to tensile axis -- size of the initial defects, composition of the concrete, and the hierarchy of toughnesses of various phases [17, 18,25,33]. Initial cracks are typically located on the aggregate-cement past interface. The first crack, which will be destabilized at some low tensile stress, will be the largest crack perpendicular to the maximum tensile stress. The other cracks will be destabilized sequentially as the external load increases. The destabilized cracks will propagate along the aggregate-cement paste interface because it has the lowest fracture toughness and will eventually be stopped at the edge of the interface by the cement paste, which

* LNETI, Lisbon, Portugal

** CEMM Department, Univ. of Illinois, Chicago, Illinois

is approximately two times tougher than the interface.

If the load is further increased, the crack will begin to propagate in a runaway fashion through the cement paste with but a slight chance of being arrested by an aggregate in its path. The crack will propagate through the aggregate only if substantial kinetic energy becomes available, as in high speed failures. This scenario has been experimentally verified using the acoustic emission method [32].

Individual bursts correspond to the unstable propagation of microcracks sequentially activated by the increasing external load. On the macroscale the process appears smooth even though kinks on the descending (softening) part of the stress-strain curve become evident when sophisticated equipment is used. These kinks correspond to the onset of localization; i.e., events associated with large amounts of released energy.

A major issue is that the underlying phenomenon is strongly dependent on the random geometry of the mesoscale. Mesoscale includes distribution of volume and surface area of aggregates, distribution of inclusions in the matrix, and distribution and orientation of initial defects. These distributions -- that is, the fabric of the mesostructure -- can be accurately ascertained using the methods of quantitative stereology [31] or a newer digitized procedure [23], but such techniques are seldom used.

ANALYTICAL METHODS

It is not surprising that almost every existing model in continuum mechanics has been used to study the dynamic strength of concrete. The apparent need for additional material parameters to define the often bewildering experimentally obtained curves was apparently a motivation of the application of complex elasto-viscoplastic models [21] even though the response of concrete is not influenced by slip but by microcracking.

For present purposes all methods can be classified as empirical, phenomenological, or micromechanical. The first group has been reviewed elsewhere [27]. A model is considered phenomenological if it establishes relations between the expected values of stresses and strains (or macrostresses and macrostrains) without direct reference to events on the lower scale. Micromechanical models (such as slip theory) are distinguished by attempts to account for the heterogeneity of the state and internal variables and the structure of the solid on the lower (or meso-) scale. The increased sophistication is almost without exception accompanied by a decrease in tractability.

The theory of plasticity or any other branch of continuum mechanics originally formulated to model the response of solids in which slip is the dominant mode of irreversible structural changes appears to be unsuitable for concrete analysis. This argument has been elaborated [17]. On the other side of the spectrum is whether or not classical fracture mechanics can be used to analyze concrete; i.e. whether the critical stress intensity factor, or energy release rate, is a material parameter has been debated [32].

Regardless of all possible modifications of the classic Griffith-Irwin theory; experimental evidence [13,20,22] indicates that most of the energy dissipated in fracture and fragmentation is associated with the evolution of microcracks, or damage, and not in propagating the macrocrack that causes ultimate loss of integrity. Whether the energy ratio is actually four to one [20] or even larger [22] is irrelevant so long as the ultimate localization process is not in fact the dominant energy sink.

A model of the impact response of concrete should include kinematic and kinetic aspects of the propagation of each crack through a strongly heterogeneous medium. Because such a task is well beyond current capabilities, an approximation based on a rational model of the actual phenomenon must be used. There appears to be little doubt that continuum damage mechanics (CDM) constitutes an appropriate framework for describing the phenomenon. Introducing a special variable that in some physically acceptable sense qualifies and quantifies the microcrack distribution -- i.e., the accumulated damage -- establishes a way to deal with the response of brittle bodies dominated by the existence and evolution of microcracks.

Unfortunately, CDM is at present prone to misconceptions and misunderstandings [16]. As a result no micromechanical theory dealing with the impact strength of concrete exists at present. Nevertheless, CDM has been used with apparent success to model explosive fracture of rocks (oil shale) [10,11]. Further modification of the model has introduced the crack inertia force [24,29]; it provides a way to reproduce with some accuracy the increase in compressive strength of concrete with increasing strain rate.

An accurate computerized model for the spalling and fragmentation of brittle solids has been formulated [7,26]. The model is based on

material models of microcrack nucleation and growth but is not cast in the form of conventional continuum theories. Another interesting model of the propagation of a macrocrack through a solid has been formulated by Chudnovsky [6]. The macrocrack interacts with a cloud of microcracks that envelope its tip. He considers the microcrack cloud to be a thermodynamic entity the evolution of which is defined by four internal variables (fluxes); i.e., translation, rotation, change of shape, and volume.

EXPERIMENTAL RESULTS

The literature on concrete [32] contains many results that are only marginally useful. Most of the experimental data, with the exception of a few recent studies, concentrates on describing the final stage; i.e., global loss of integrity of the specimen. Moreover, even though the nonlinear response of a concrete specimen and its ultimate strength depends on the mesostructure of the concrete -- distribution of aggregate size, distribution and type of initial defects, hierarchy of toughnesses; data are seldom listed.

Even experimental evidence dealing with less sensitive aspects is by the nature of the phenomenon inherently inconclusive. For example, the scatter of experimental results for the biaxial strength of concrete [9] precludes meaningful conclusions of the phenomenon such as assessing the influence of interaction of microcracks in two planes. It has been pointed out [12] that boundary conditions on the loading device-specimen interface are the most important reason for the lack of conclusive results. Indeed, scatter will persist regardless of the type of device so long as the mesostructure of a specimen is not taken into account. The influence of aggregate size distribution must be the first obvious target [3].

It is thus not unexpected that dynamic tests show even greater scatter. For example, even the trends relating strain rate and dynamic to static strength of concrete differ [12]. Some curves are convex, some are concave, and some do not show any increase in dynamic strength until very high strain rates are achieved. Any analytical model will reproduce with minor tuning at least one of these trends.

Impact fatigue data are scarce with few exception [4,5,14,28]. The problem is exacerbated by the strong size effect that inhibits direct correlation between test results and the fatigue life of an actual structure. For example, in the course of tests on breakwater cubes [28] is was ascertained tha. the number of impacts to fracture decreased by an order of magnitude during transition from a relatively small (1 tf) to a large cube (7 tf).

None of these tests concentrated on estimating the increase in damage with each impact. Some relatively crude ultrasonic measurements during breakwater cubes tests showed a decided decrease in sound velocity, especially in the direction perpendicular to the expected microcrack planes. Only a comprehensive system of tests leading to reliable qualitative and quantitative estimates of microcrack distribution and growth will, however, provide a useful basis for the development of useful theoretical models.

Analytical modeling of the tests has been performed at an elementary level [19,29]. The problem involves determination of the stress wave propagating through concrete. In order to make the problem tractable it is necessary to assume that the waves propagating through the concrete are plane; i.e., waves emanating from the lateral surfaces are neglected. It is by no means certain that the change in the wave front will be affected more by microcracks than by the lateral surfaces. Thus, the complexities of the physical problem are such that conclusive answers to various questions remain an elusive goal.

SUMMARY AND CONCLUSIONS

The goal of this short review was to raise more questions than it was able to answer. It is not meant as a comprehensive review of the literature.

The main conclusion is that the problem of impact strength and dynamic fatigue of concrete is so complex that it defies present capabilities to obtain a solution. The lack of comprehensive and well-documented experimental data hinders the development of analytical models. Even if continuum damage mechanics is a logical way to attack the problem, the formulation of a believable model hinges on understanding and reproducing microdefect kinetics in a strongly heterogeneous material. In all probability a stochastic description of the mesostructure of a solid offers the most realistic approach to the formulation of such a model. The same strategy will be necessary for an analytical model of the size effect [17] that constitutes a necessary step for correlating test specimen and prototype.

ACKNOWLEDGEMENTS

The cooperation on this paper was made possible by NATO travel grant number 099-84 to the two

authors. The work of one of the authors (D.K.) was sponsored by the AFOSR grant to the University of Illinois, Chicago. Both grants are gratefully acknowledged.

REFERENCES

1. Adeli, H. and Sierakowski, R.L., Shock Vib. Dig., 17 (9), p 3 (1985).

2. Ashby, M.F., Fracture Mechanics, R.A. Smith (ed.), Pergamon Press, Oxford (1979).

3. Birkimer, D.L. and Lindeman, R., ACI J., p 47 (1971).

4. Burcharth, H.F., Coastal Engineering, 4, p 229 (1981).

5. Burcharth, H.F., Bull. No. 18, Lab. Hydraulik og havnebygning, Aalborg Universitetscenter, Denmark (1981).

6. Chudnovsky, A., Case Western Reserve Univ., NASA Contractor Rep. 174634 (1984).

7. Curran, D.R., Shockey, D.A., and Seaman, D.L., J. Appl. Phys., 44, p 4025 (1973).

8. Davison, L. and Graham, R.A., "Shock Compression of Solids," Physics Rep., 55 (4), p 257 (1979).

9. Gerstle, K.H. et al., Douglas McHenry Intl. Symp. Concrete, Concrete Struct., Publ. Sp.-55 (1976).

10. Grady, D.E. and Kipp, M.E., Proc. 20th U.S. Symp. Rock Mech., Austin, TX (1979).

11. Grady, D.E. and Kimm, M.E., Intl. J. Rock Mech. Min. Sci. Geomech. Abstr., 17, pp 147 (1980).

12. Hagemier, G.A. and Read, H.E., Workshop on Inelastic Deformation and Failure Modes, Northwestern Univ., Evanston, IL (1984).

13. Hoagland, R.H., Hahn, G.T., and Rosenfield, A.R., Rock Mechanics, 5, p 77 (1973).

14. Kormeling, H.A., Zielinski, A.J., and Reinhardt, H.W., Rept. No. 5-80-3, Delft Univ. of Technology, Stevin Lab. (1980).

15. Krajcinovic, D., Shock Vib. Dig., 14 (11), p 3 (1982).

16. Krajcinovic, D., Appl. Mech. Rev., 37, p 1, (1984).

17. Krajcinovic, D., Mechanics Today (to be published).

18. Krajcinovic, D. and Fanella, D., Engrg. Fracture Mechanics (to be published).

19. Krajcinovic, D. and Silva, M.A.G., Intl. J. Impact Engrg., 2, p 331 (1984).

20. Meyers, M.A., Mechanics of Matls. (to be published).

21. Nilsson, L., "Impact Loading on Concrete Structures," Publ. 79: 1, Chalmers Univ. Technology (1979).

22. Pak, A.P. and Trapeznikov, L.P., Advances in Fracture Research (Fracture 81), 4, p 1531, D. Francois (ed.), Pergamon Press (1982).

23. Panozzo, R.H., Tectonophysics, 95, p 279 (1983).

24. Passman, S.L., Grady, D.E., and Rundle, J.B., J. Appl. Phys., 51, p 4070 (1980).

25. Santiago, S.D. and Hilsdorf, H.K., Cement and Concrete Research, 3, p 363 (1973).

26. Shockey, D.A. et al., Intl. J. Rock Mech. Min. Sci. Geomech. Abstr., 11, p 318 (1974).

27. Sliter, G.E., ASCE J. Struc. Engrg., 106, p 1023 (1980).

28. Silva, M.A.G., Coastal Structures 83, ASCE Spec. Conf., Washington, D.C. (1983).

29. Suaris, W. and Shah, S.P., Rept. to Interassoc. Symp. Concrete Structures under Impact and Impulsive Loading, Berlin (1982).

30. Suaris, W. and Shah, S.P., ASCE J. Engrg. Mech., 110, p 985 (1984).

31. Underwood, E.E., Quantitative Stereology, Addison Wesley (1970).

32. Wittmann, F.H., ed., Fracture Mechanics of Concrete, Elsevier (1983).

33. Zaitsev, Y., Deformation and Strength Models for Concrete Based on Fracture Mechanics, Stroiizdat, Moscow (1982).

34. Zukas, J.A. et al., Impact Dynamics, John Wiley & Sons (1982).

LITERATURE REVIEW: survey and analysis of the Shock and Vibration literature

The monthly Literature Review, a subjective critique and summary of the literature, consists of two to four reviews each month, 3,000 to 4,000 words in length. The purpose of this section is to present a "digest" of literature over a period of three years. Planned by the Technical Editor, this section provides the **DIGEST** reader with up-to-date insights into current technology in more than 150 topic areas. Review articles include technical information from articles, reports, and unpublished proceedings. Each article also contains a minor tutorial of the technical area under discussion, a survey and evaluation of the new literature, and recommendations. Review articles are written by experts in the shock and vibration field.

STATIC AND DYNAMIC BEHAVIOR OF MECHANICAL COMPONENTS ASSOCIATED WITH ELECTRICAL TRANSMISSION LINES — II

P.G.S. Trainor*, N. Popplewell*, A.H. Shah*, and C.K. Wong**

Abstract. This article describes the behavior of electrical transmission towers, insulator strings, and conductors as determined from theoretical analyses, and from model and full-scale tests. Wind loads, ice deposition, and the important topic of overall line reliability are reviewed as well.

A previous paper [1] gave a perspective of the multi-disciplined [2] research underlying the mechanical design of electrical transmission line components. The present update is somewhat less broad-based because it concentrates on recent literature. Research articles are discussed under the following headings:

- Probability calculations and structural reliability
- Wind and ice loading
- Dynamic analysis
- Development of new structural components

PROBABILITY CALCULATIONS AND STRUCTURAL RELIABILITY

Structural designers of transmission line systems are moving rapidly toward an approach based on detailed statistical assessment of reliability. The thrust for this development is the intrinsically greater vulnerability of transmission lines compared to such civil engineering structures as bridges and buildings. This vulnerability is due in part to the critical nature of each connected component and in part to the length of a transmission line. For instance, the failure of a conductor, insulator, crossarm, tower, or foundation causes a complete and sudden withdrawal of electric power. A longer line increases chances that a component will have a low strength or a statistically extreme climatic load. Elimination of all possible failures is thus not economically feasible. However, a more refined statistical design process has the potential to produce more consistent and therefore cost-beneficial designs.

Although there is no disagreement about the potential benefits of a statistically based design, two distinct suggestions for implementing the concept have been made. One is the load and resistance factor design (LRFD) favored by the ASCE. This method is an extension of that developed in building codes. The more novel approach of the International Electrotechnical Commission (IEC-TC11) is based partly on research at Hydro Quebec [7,8].

The LRFD approach has the advantage of being familiar to most graduate structural engineers. However, the application is generally a formality in building design because the load and resistance factors that must be applied to nominal loads Q and nominal strengths R are specified uniquely in codes. On the other hand, the choice of factors in a transmission line design must reflect the overall importance of the line or the relative importance of an individual component. In other words, each design factor must be linked simply, but with reliable consistency, to the probability of failure.

One way of accomplishing such a link is to express the load and resistance factors in terms of reliability indices β [3,4]. The appropriate values of β for each component under a particular sustained loading can then be potentially established by calibration with existing lines. This calibration process might overcome inaccuracies arising from the computation of β by approximate, first-order statistical methods [3].

Alternatively, a more advanced approximation known as the design point method has now been proposed. This method gives values for the probability of failure, or alternatively β, that agree well with exact mathematical simulations like the Monte Carlo method. Thus, the design point method enhances the possibility of incorporating a specified target reliability within the LRFD framework.

A 1984 ASCE publication [5] contains tables that link the sensitivity of the probability of failure P_f to a change in the load and resistance factors. The base annual probability of failure P_0 is not known accurately. However, detailed statistical studies [6] have shown that the relative adjustment of P_f can be expressed reasona-

* University of Manitoba, Winnipeg, Canada

** Senior Structural Engineer, Manitoba Hydro, Winnipeg, Canada

bly by the uncoupled equation $P_f = P_0/CG$. C is the component factor representing the reliability adjustment controlled by the strength factors; G is the corresponding adjustment of the load factors.

Ghannoum [7] has advocated the systems design approach of IEC-TC11 and compared it with LRFD. A major difference in the systems approach is that the starting parameter is the acceptable target reliability of the line (system) rather than the reliability of an individual component. It may seem that very complex methods would be needed to calculate the overall reliability of a line. However, the calculations are simplified by implementing a preferred sequence of failure under the design loads. Consequently, the reliability of the line becomes equal to that of the weakest components. For economic reasons, and to avoid cascading, the weakest component is usually the tangent suspension towers. Therefore, detailed statistical analyses should concentrate on such tower components.

Ghannoum does not urge a sudden change from existing methods of design. But he does recommend that accurate second-order statistical methods, such as a Monte Carlo simulation or numerical integration, should be used to elucidate trends that feed back into the design process. Such feedback is also encouraged by the format of IEC-TC11; it relates loads to design strengths by using concrete statistical concepts rather than abstract factors. The design strengths are set uniquely at 10% R or 10% $MIN_N R$. Ten percent R depicts the 10% exclusion limit (90% withstand value) for a batch of components tested individually. Ten percent $MIN_N R$ represents the 10% exclusion limit for N components loaded simultaneously by climatic forces. In addition, the designated loads Q always correspond to an equivalent return period T_e that is the average number of years between events producing loads greater than or equal to Q. Ghannoum [7] admits that the computation needed to evaluate the design value of T_e may be fairly involved. However, the concept of a return period is familiar to transmission line engineers.

The potential advantages of a systems analysis can be seen in an earlier paper by Ghannoum [8]. He used exact statistical techniques to elucidate for the first time the significance of the span use factor U. The U for a tower is defined as the ratio of the actual span, dictated by tower spotting, to the maximum design span for that tower in the given region. Ghannoum incorporated various statistical distributions with extremes between 0.4 and 1.0 to represent typical construction practice. He found that a dispersion of U below 1.0 does not significantly decrease the probability of failure of a line. Therefore, it may be cost beneficial to increase the number of tower designs (each with a different strength) to achieve a dispersion of U very close to 1.0. The important proviso was that five of more towers should be affected when the climatic extreme load actually occurs. Thus, the statistical analysis has been shown useful, although it has also generated some controversy about the geographic extent of extreme loads.

Ghannoum [8] considered that loads affecting five or more towers may arise from freezing rain, tropical storms, or hurricanes and strong winds over flat terrain. On the other hand, it has been argued [9] that winds typically causing tower failure are due to local thunderstorms or squalls that may have a front as small as 300 meters. In that case, towers with low use factors can be removed from the population at risk and, as a consequence, the distribution of U will have a significant effect on the overall reliability of a line.

WIND AND ICE LOADING

The magnitudes of extreme wind and ice loads and their corresponding mean recurrence intervals have been widely researched. Meteorological records have shown that high wind speeds usually follow an extreme type I statistical variation. This type of distribution is also used to model ice formation on conductors although there is then more dispersion in the statistics. In other words, the difference between the ice load for a 50-year return period and that for a 100-year return period is much more significant. A detailed set of example calculations illustrating the conversion of meteorological data into probability density functions for transmission line loading is available [10]. The case of a moderate wind acting on iced lines is also considered because this tricky situation may govern the design of towers.

Two difficulties encountered in the processing of wind data are a lack of long-term records and uncertainties about the directional variation of extreme wind speeds. However, the use of three to five year records to estimate wind speed with a 50-year average recurrence interval v_{50} has been shown reasonable in the United States [11]. Apparently, the use of yearly extreme wind speeds tends to lead to underestimations of v_{50}. Estimates from monthly extremes are much better even though there may then be some seasonal influence. The possibility of inaccurately computing the maximum wind in a given

direction arises because of the nature of published data. For instance, a 69 mph (115 km/h) wind blowing from the east will not be published if the wind switches to northerly at 70 mph (117 km/h) on that day. Nevertheless, an exhaustive study [12] of unpublished data led to the conclusion that yearly, fastest-mile directional wind speeds may be reasonably employed providing records have been kept at least 20 years.

Probabilistic calculations concerning tornadic wind speeds have been made possible because Canadian and United States weather agencies have established data bases containing significant characteristics of every tornado reported since 1950 [13]. The data include the time of occurrence, touchdown and lift-up points, track length, and path length of each storm. It has been pointed out [14] that 50% of the tornadoes in the United States have peak winds of less than 103 mph (172 km/h); 80% have peak winds of less than 135 mph (225 km/h). Therefore, the layman's presumption that tornadic winds are typically much more severe than extreme wind gusts is erroneous. However, detailed theoretical modeling [14] has shown that a transmission line has a critical length as short as ten miles. When the line is longer, its interception by a wind speed greater than a typical design value of 80 to 100 mph (130 to 170 km/h) is more likely to be caused by a tornado than a regular wind front. A more specific study in Ontario used local data on tornadoes to estimate the frequency of simultaneously losing all the electrical circuits in a single power corridor [13]. The computed frequency was stated to be within one standard deviation of the historical data. A later study [15] simulated the possibility of losing, due to the same tornado, two parallel power corridors separated by 5, 10, 20, or 50 km. It was found that a separation of 5 km increased the frequency of losing both lines by an order of magnitude compared with a 50 km separation. On the other hand, raising the separation from 5 to 10 km decreased the frequency by only 26%.

Ice loading is generally less well understood than wind loading. Three icing phenomena can cause damage: freezing rain, atmospheric or in-cloud icing, and the adhesion of wet snow. One of these phenomena usually dominates in a particular geographical region. The flow of freezing rain around a conductor causes highly asymmetrical ice shapes that make the conductor more prone to galloping. However, an assessment of ice load must rely largely on specimens collected during extreme storms.

On the other hand, in-cloud icing, which occurs in mountainous regions, is a more frequent process. Deposition occurs over several hours or days due to the collision of moist air with the windward side of the conductor. However, the ice deposit becomes well rounded because the conductor rotates even under very small eccentric gravitational forces. A heat-balance model constructed by Makkonen [16] showed that the growth of ice is extremely nonlinear even under constant atmospheric conditions. Ice accretion invariably starts with a high-density, wet growth (glaze); excess moisture drips off the line. After several hours, however, a transition to dry growth (rime) occurs. Because the simulated accretion showed that the process is very complex, it was suggested that routinely measured meteorological parameters such as wind speed and air temperature cannot accurately predict ice buildup.

Another study investigated the effect of the electric field emanating from a HVDC line [17]. Test results suggested that the presence of a high-voltage AC or positive DC current does not significantly affect ice accretion. However, a delicate tree-like pattern forms on the negative DC conductor due to corona discharge. As a result, the weight of ice is much smaller on the negative conductor.

Wet snow accretion is not perceived as a widespread problem, perhaps as a consequence of the tendency of snow to blow off a line. On the other hand, failures have been reported in coastal regions of the U.K. and Japan. Indeed, experiments [18] have shown that the deposit may become somewhat circular because wet snow slides around the conductor and clings to its underside. Surprisingly, accumulations of up to 10 cm in diameter and high densities of 0.5 gm/cm^3 were achieved.

DYNAMIC ANALYSIS

A general discussion regarding the types of dynamic load affecting transmission line systems has recently been published [19]. Topics include wind gusts, conductor vibrations, and longitudinal loads due to component failure or ice shedding. It was emphasized that characteristics of each line system determine the longitudinal (along-line) loads. Therefore, dynamic tests of individual tower design were recommended. Although few national testing facilities are apparently designed to facilitate dynamic tests [20,21], there has been no corresponding documentation of results. However, EPRI has recently commissioned comprehensive dynamic testing of towers at the Transmission Line Mechanical Research Facility [22]. Such tests will allow engineers to

evaluate the relative performance of different tower designs.

For the present, engineers may wish to carry out a preliminary dynamic analysis based on estimates of the dynamic characteristics of a tower. For instance, the lowest bending and torsional natural frequencies of a lattice transmission tower can be calculated using a straightforward Dunkerley procedure [23]. The analysis is based on tapered beam flexibilities and produces frequencies within 10% of those given by a very detailed finite element model.

The control of longitudinal loads is important. Indeed, the failure of a component due to longitudinal loading could lead to progressive collapse of adjacent towers. A review of this phenomenon is available [24]. The author favors use of special conductor clamps that reduce tower forces by allowing the conductors to slip at a designated limit load. Hence, the clamps are structural fuses. A similar concept has been described [25] in which some short and even long cascades have resulted from large longitudinal loads applied by fallen towers to ground wire attachment points on top of adjacent towers. The tower peaks were thus designed to fail before the towers themselves. On the whole, current design practice does not place much emphasis on dynamic loads induced by cascading because this effect is claimed to be reduced by successive failures of energy absorbing towers [24]. However, the important question of the number of tower failures required to produce a significant load reduction is left unanswered. The answer will presumably depend upon the particular dynamic characteristics of the towers involved and the timing of the gravitational and strain energy release from each successive conductor span.

In the case of a broken conductor, the simplest estimate of the peak load due to conductor recoil may be determined from tabulated experimental results. It is well known that impact factors relate to conductor tension, span, and insulator length. However, actual deformations and stress resultants in the tower depend significantly upon the temporal history of the impact load, which usually exhibits two large peaks. Such histories can be simulated by using numerical integration to generate the nonlinear recoil of the conductors and the corresponding swing of the insulators. However, simplifications are necessary in order to reduce computational effort. A single conductor system has been modeled [26] by employing three spans adjacent to the break. The first tower was represented by a spring although there were 35 nonlinear cable elements and three insulators in the computer model. The loading histories that were generated agreed well with experiments. The method can be used on a microcomputer [27]. However, the major assumption that the dynamic response of the tower -- which requires a separate analysis -- does not feed back to affect the pattern of the loading is largely untested. A much more detailed model of the tower has been carried out [28]; all conductors and groundwires were considered. Indeed, this computer program is capable of directly providing such response data as ground-line bending moment. The conductor model was restricted to one element per span. It is unlikely that such a simplification is adequate to model the longitudinal and transverse wave propagation that actually occurs in the conductor.

The additional tension generated by the dynamic response of conductors is also important in determining the earthquake-generated response of towers [29]. The frequency range considered for such excitations is predominantly from 0.1 Hz to 8 Hz. The theoretical, along-line dynamic spring stiffness of the conductor fluctuates wildly because of the proximity of the transverse modes of vibration of the conductor. However, it has been shown [29] that only three of these resonances had broad peaks for a typical conductor span. The corresponding modes were the sixth transverse mode (a special crossover mode at 0.62 Hz), the first longitudinal mode at 4.2 Hz, and the second longitudinal mode at 8.3 Hz. It was concluded that the calculation of additional tensions induced by earthquakes could be simplified by neglecting all the other modes.

Conductor motions arising from aeolian vibration or galloping have been studied in another review [30]. Nevertheless, several brief comments are relevant. A recent study surveyed damage caused by conductor galloping [31]. Responses from utilities in Japan, New Zealand, the United States, Canada, and Europe indicated that the failure of crossarms is common. The greatest damage seems to occur at running angle suspension towers and at steel lattice towers with dead-ended conductor connections. Furthermore, half the respondents were concerned that an increase in the occurrence of galloping may be related to the progressive aging of lines. This observation is by no means conclusive and no cause has been proposed. However, it is of interest that the outermost layer of an ACSR conductor is able to slide over the penultimate layer during flexure [32]. Because the maximum bending stresses occur in the penultimate layer, damage may go unnoticed. Furthermore, this freedom to slide -- which changes with spanwise

position -- is said to be responsible for most of the damping in ACSR.

An unusual form of conductor vibration induced by rainfall is caused by corona discharge on hanging water droplets [33]. Synchronization occurs between corona discharge and the motion of the conductor. The conductor continues to vibrate after an interruption of precipitation, presumably until the droplets evaporate. However, the typical magnitudes of the conductor vibration have not been studied in detail, and it is unclear whether the mechanism has the potential to cause damage.

DEVELOPMENT OF NEW STRUCTURAL COMPONENTS

The desire for power transmission in increased bulk has promoted studies on possible new configurations for lines and support structures. There has also been interest in the compaction of conventional lines by using reduced clearances between conductors and lower towers. The resulting stimulation of research into the behavior of conductors, insulators, and towers has also benefited standard designs.

The most traditional method of increase in power bulk has been to steadily increase voltages of the standard three-conductor (or phase) AC transmission. However, the ensuing increased electrical clearances lead to larger rights of way on the ground; furthermore, traditional support structures must have wider crossarms and consequently much more strength. Lines at 735 kV are operational. Extensions of 1200 kV, on the other hand, have not yet been made although test sections have been constructed [34].

An alternative is to use high phase order transmission [35,36] with six or twelve conductors per circuit. An advantage of this approach is that the right of way can be decreased by arranging the conductors in a relatively circular pattern. Such an arrangement necessitates radical changes in both the support structures and insulator systems that could initially prejudice the reliability of a line. Construction of these lines is not likely to occur in the near future because of a generally decreasing growth in power requirements.

It has been suggested [34] that a more practical alternative is to use HVDC transmission because the associated support structures are inherently lighter than their AC counterparts. The mystique surrounding the application and design of HVDC seems to be rapidly disappearing, and several new schemes could be active by 1990. The cost benefits of converting a double circuit 230 kV AC line (six conductor) to a +/- 400 kV DC (two conductor) line have been shown [34]. The resulting power transfer increase is almost 6:1, yet modifications to the support structures are relatively straightforward and cheap. Much of the expense, however, could come from upgrading converter stations at each end of the line.

One illustration of the vigorous amount of testing required to validate any new support tower is available [38]. The word chainette is used to allude to the fact that a crossarm of the tower is not rigid but consists of an array of wire cross ropes suspended between two guyed posts. The system is economically feasible to support large bundled conductors in fairly flat terrain, providing a wide right of way is permissible. The remarkable feature of this tower is its flexibility under vertical loads. For instance, 30 mm of radial ice on a 500 m span can cause the attachment point of a conductor to drop by more than 1.5 m [37]. It thus seemed advisable to employ both scale-model and full-scale tests to determine the resistance of such a tower to dynamic loads. Simulation of broken guys, broken conductors, ice shedding, and galloping by Hydro Quebec in 1976 proved that the concept was sound.

Other utilities have recently performed their own designs and analyses [38-41], and this type of structure is now accepted more widely. The pluck excitation of towers and conductors in a full-scale test line [41] confirmed that the coupling supplied by cross ropes did not adversely affect the response of the system to galloping. However, it was suggested (but not confirmed) that there might be a greater tendency for the system to vibrate in the subconductor oscillation range of frequencies at about 1 Hz.

The compaction of standard AC transmission line configurations has been stimulated by significant progress in the prediction of the dielectric withstand of air gaps. It has been suggested [42] that new 400 kV lines in France can be compacted to roughly the size of existing 225 kV designs. However, the less conservative phase-to-phase clearances depend upon relative motions at midspan caused by dynamic ice shedding, uneven static ice, switching overvoltage, wind loading, and short circuit. It was shown that a short circuit causes a complex electrodynamic movement and that conductor spacing must be sufficient to avoid clashing. On the other hand, wind excitation causes a relative approach of two adjacent horizontal conductors due to swinging motions. Detailed experimental and analytical

studies [43] have shown that the change in spacing is less than the magnitude of the absolute swing of a conductor because of the correlation between wind forces.

Reducing the height of transmission towers depends upon an ability to control conductor sag. Initial sag, which is determined at stringing, is governed by the need to limit tension. The tension limit is usually only about 20% of the conductor's ultimate tensile strength (UTS) because higher values can lead to fatigue induced by aeolian vibration. It may be possible to increase the UTS of conductors by carefully optimizing manufacturing processes [44].

An alternative procedure is to better control the vibrations. For instance, it has been claimed that the T2 motion resistant conductor [45] reduces both aeolian vibration and galloping. The system consists of two standard conductors twisted about each other with a twist length of about three meters. A drawback is that increased wind drag and ice loading would necessitate undesirable strengthening of the tower. In contrast, attempts have been made to reduce the bulk of towers by minimizing the drag forces on a standard conductor [46]. The conductor surface is constructed more smoothly than a regular ACSR but not too smooth. In effect, the local minimum in the plot of drag force against wind speed is shifted so that it occurs in the vicinity of typical design wind speeds. Full-scale tests show a potential for a 20% reduction of wind forces.

The operating sag of a transmission line depends upon the temperature of the conductor. The temperature depends, in turn, upon operating current, wind speed, wind direction, and ambient temperature. Therefore, most utilities rate the current in their lines according to an assumed set of weather conditions. However, real time predictions of temperature and sag are possible [47]. Experiments on a full-scale conductor span showed that data from a simple and inexpensive weather station was sufficient to allow computerized projections to within +/- 10°C of the actual temperature of the line. Surprisingly, it was found that maximum conductor temperature was frequently at night because of reduced wind velocity. This situation can occur even though solar radiation is absent and the electric current may be lower. Significant economic and safety benefits are associated with the ability to predict instantaneous clearances for various conductor loadings and weather conditions.

Composite insulators are now more widely used. They consists of a resin-bonded fiberglass rod and metal end fittings. The rod is covered with a flexible rubber shed to resist electrical stresses induced by weather. Such insulators are advantageous because they are lightweight, resilient in bending, less obtrusive visually, and do not shatter under gunfire. However, their electrical and mechanical behaviors are more complicated than those of analogous porcelain insulators because organic materials are susceptible to aging. Although the technical aspects have been outlined [48,49], it is more convenient to summarize the important mechanical considerations by discussing recent research papers.

Tensile tests on composite insulators have shown that short-term tensile resistance depends upon the design of metal end fittings [50] and that failure occurs due to stress concentrations. Three types of fittings performed adequately with ultimate tensile strengths (UTS) in the 500-700 MPa range. A fourth fitting described as a tapered design, resulted in a strength of only 270 MPa. Tests were also undertaken at four temperatures in the range of -25°C to 100°C. Fracture patterns changed and strengths invariable decreased with temperature. However, a more significant factor is the approximately linear decrease of strength with the logarithm of the application time of load [51,52]. For instance, it has been shown [51] that sustained loads that will produce rupture in one month are approximately 30% lower than the initial UTS. On the other hand, an extrapolation of test curves suggested that test specimens could withstand 55% of the initial UTS for 50 years or more.

Service experience with composite insulators has shown that failures do not correspond to those produced by tensile tests [52,53]. Failures were of a brittle nature and occurred primarily on horizontal insulator strings at anchor towers. It was found [53] that bending fatigue tests could reproduce these types of failures. However, another study [54] has shown that such brittle fractures are produced by a constant bending stress in the presence of stress cracking agents such as water and particularly nitric acid. The possibility of removing a composite insulator from service and determining its previous load history has been explored by measuring the acoustic emission (AE) from tensile tests [55]. It was claimed that a transition in the AE rate can indicate the previous maximum load. There appeared to be some memory loss with time, but the previous maximum load could apparently be detected after one year.

The service behavior of composite insulators has been reasonable thus far. However, widespread

application may not occur until they have the proven reliability of porcelain insulators. Nevertheless, the latter are not entirely problem free. For instance, Ontario Hydro replaced thousands of insulators in the early 1980s in their transmission and distribution networks due to the discovery of latent defects [56]. The principal cause was said to be the expansion of cement in the insulator pin holes that led to cracking of the porcelain heads. The expansion was caused by direct wetting from rain or melting ice, so that the problem affected only the horizontal (dead end) insulator strings.

Another innovation now being introduced on overhead lines is a composite ground wire containing a core of optical fibers. Such fibers can be used conveniently to provide protection and control of a power system through telecommunication between substations. Various prototype line sections have been installed with lengths up to five km [57-60]. Like regular ground conductors, the new composite wires must withstand ice, wind, galloping, and high temperatures induced by short circuit faults. However, the strain on the optical fibers must be minimized; otherwise signal attenuation occurs. Most designs incorporate the fibers in a protective aluminum tube [57-59] although a plastic core reinforced with steel has also been used [60]. The concept is still in an evolutionary stage although the prototypes are apparently working well.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial support of the Manitoba HVDC Research Centre.

REFERENCES

1. Trainor, P.G.S., Popplewell, N., Shah, A.H., and Pinkney, R.B., "Static and Dynamic Behavior of Mechanical Components Associated with Electrical Transmission Lines," Shock Vib., Dig., 15 (6), pp 27-38 (June 1983).

2. Adam, J.F., Bradbury, J., Charman, W.R., Orawski, G., and Vanner, M.J., "Overhead Lines -- Some Aspects of Design and Construction," IEE Proc., 131 (5), pp 149-187 (Sept 1984).

3. Goodwin, E.J., Mozer, J.D., and DiGioia, A.M., "Transmission Structure Design Utilizing Probability-Based Load and Resistance Factor Design," IEEE, Trans. PAS 102, pp 1590-1597 (June 1983).

4. Mozer, J.D., Peyrot, A.H., and DiGioia, A.M., "Probabilistic Design of Transmission Line Structures," ASCE J. Struc. Engrg., 110 (10), pp 2513-2528 (Oct 1984).

5. ASCE Committee on Analysis and Design of Structures, "Guidelines for Transmission Line Structural Loading," Prepared by the Committee on Electrical Transmission Structures, ASCE, New York, NY (1984).

6. Peyrot, A.H. and Dagher, H.J., "Reliability-Based Design of Transmission Lines," ASCE J. Struc. Engrg., 110 (11), pp 2758-2777 (Nov 1984).

7. Ghannoum, E., "Improving Transmission Line Design by Using Reliability Techniques," IEEE, Trans. PAS, 103 (10), pp 3144-3152 (Oct 1984).

8. Ghannoum, E., "Probabilistic Design of Transmission Lines; Part I: Probability Calculations and Structural Reliability;" "Part II: Design Criteria Corresponding to a Target Reliability," IEEE, Trans. PAS, 102 (9), pp 3057-3079 (Sept 1983).

9. White, H.B., "A Practical Approach to Reliability Design," IEEE, Trans. PAS, 104 (10), pp 2739-2747 (Oct 1985).

10. Krishnasamy, S.G., "Assessment of Weather Induced Transmission Line Loads on a Probabilistic Basis," IEEE, Trans. PAS, 104 (9), pp 2510-2516 (Sept 1985).

11. Grigoriu, M., "Estimates of Extreme Winds from Short Records," ASCE J. Struc. Engrg., 110 (7), pp 1467-1484 (July 1984).

12. Simiu, E., Hendrickson, E.M., Nolan, W.A., Ingram, O., and Spiegelman, C.H., "Multivariate Distributions of Directional Wind Speeds," ASCE J. Struc. Engrg., 111 (4), pp 939-943 (Apr 1985).

13. Anders, G.J., Dandeno, P.L., and Neudorf, E.G., "Computation of Frequency of Right-of-Way Losses due to Tornadoes," IEEE, Trans. PAS, 103 (9), pp 2375-2381 (Sept 1984).

14. Twisdale, L.A. and Dunn, W.L., "Probabilistic Analysis of Tornado Wind Risks," ASCE J. Struc. Engrg., 109 (2), pp 468-488 (Feb 1983).

15. Anders, G.J., Dandeno, P.L., and Neudorf, E.G., "Frequency of Losing Two Rights of Way due to Tornadoes," Can. Elec. Engrg., J., 10 (2), pp 50-53 (Apr 1985).

16. Makkonen, L., "Modeling of Ice Accretion on Wires," J. Climate Appl. Meteorology, 23 (6), pp 929-939 (June 1984).

17. Phan, L.C., Laforte, J.-L., and Nguyen, D.D., "Comparative Study of Icing on DC and AC Transmission Lines," Canadian Commun. Energy Conf., Montreal, Que., Canada, 13-15 Oct, 1982 (New York, USA: IEEE 1982), pp 139-142 (in French).

18. Kuroiwa, D., Nakayama, M., Shinoda, T., Nanba, K., and Susukida, H., "Study on Snow Accretion on Various Power Transmission Lines," Showa Wire and Cable Rev., 33 (2), pp 55-66 (1983) (in Japanese).

19. Alt, K., Bauer, K.-H., Boos, K.-V., Jürdens, C., and Paschen, R., "Dynamic Effects on Transmission Lines," Proc. CIGRE 30th Session (1984).

20. Susendran, R., Krishnamurthy, P., and Jairam, C.P., "Testing of Transmission Line Towers," Elec. India, 24 (13), pp 11-16 (July 1984).

21. Yakovlev, L.V., "Testing of High-Voltage Line Supports under Various Load Conditions," Soviet Power Engrg., 10 (11), pp 1461-1468 (Nov 1981).

22. Nair, P.K. and Lyons, P.L., "Overview of the Shakedown Testing at the Transmission Line Mechanical Research Facility," Proc. Amer. Power Conf., 45, pp 657-689 (1983).

23.Trainor, P.G.S., Popplewell, N., Shah, A.H., and Wong, C.K., "Estimation of Fundamental Dynamic Characteristics of Transmission towers," IEEE, Trans. PAS, 104 (3), pp 681-689

24. Militaru, P., "Prevention of Cascade Failures of the HV Lines Towers," Bull. Inst. Stud. Project Energ. (Rumania), 27 (1), pp 41-56 (1984).

25. Behncke, R. and White, H.B., "The Alicura 500 kV Transmission System," Proc. CIGRE 30th Session, 1 (22-02) (1984).

26. Thomas, M.B. and Peyrot, A.H., "Dynamic Response of Ruptured Conductors in Transmission LInes," IEEE, Trans. PAS, 101 (9), pp 3022-3027 (Sept 1984).

27. Peyrot, A.H., "Microcomputer-Based Nonlinear Structural Analysis of Transmission Line Systems," IEEE, Trans. PAS, 104 (11), pp 3236-3244 (Nov 1985).

28. Siddiqui, F.M.A. and Fleming, J.F., "Broken Wire Analysis of Transmission Line Systems," Computers Struc., 18 (6), pp 1077-1085 (1984).

29. Ijima, K., Kotsubo, S., Takanishi, T., and Sonoda, T., "Frequency Characteristics of Spring Constants of a Suspended Transmission Line," Memoirs Faculty Engrg., Kyushu Univ., 44 (2) (June 1984).

30. Dubey, R.M. and Sahay, C., "Vibration of Overhead Transmission Lines IV," Shock Vib. Dig., 15 (12), pp 11-15 (Dec 1983).

31. Gibbon, R.R., Juul, P.H., White, H.B., and Wijker, W.J., "Damage to Overhead Lines Caused by Conductor Galloping," Electra, (94), pp 71-76 (May 1984).

32. Gopalan, T.V. and Nagabhushana, G.R., "Flexural Rigidity of Stranded Cables," Shock Vib. Dig., 17 (6), pp 17-20 (June 1985).

33. Farzaneh, M. and Phan, L.C., "Vibration of High Voltage Conductors Induced by Corona from Water Drops or Hanging Metal Points," IEEE, Trans. PAS, 103 (9), pp 2746-2752 (Sept 1984).

34. Fullerton, F.M. and Flugum, R.W., "Advanced Support Systems and Conductor Concepts for Transmission Line," Proc. Amer. Power Conf., 45, pp 652-656 (1983).

35. Grant, I.S. and Stewart, J.R., "Mechanical and Electrical Characteristics of EHV High Phase Order Overhead Transmission," IEEE, Trans. PAS, 103 (11), pp 3380-3385 (Nov 1984).

36. Barbarito, M., Clerici, A., Giglioli, R., Paris, L., and Marsi, B., "Compact versus Conventional EHV Lines: Technical and Economical Comparisons," Proc. CIGRE 30th Session, 1 (22-13) (1984).

37. Ghannoum, E. and Lamarre, M., "Hydro-Quebec's Experience with the Design and Construction of 1500 KM of 735 KV Chainette Transmission Lines," IEEE, Trans. PAS, 104 (10), pp 2832-2843 (oct 1985).

38. Retallack, R.L., "The Chainette Structure Concept," Proc. Amer. Power Conf., 44, pp 660-664 (1982).

39. Dulis, J.E. and Shuping, R.Y., "Design of 500-kV Transmission Line Cross-Rope Suspension Structure," Proc. Amer. Power Conf., 44, pp 665-670 (Apr 1982).

40. Marsico, R., Ryan, R.D., and Retallack, R.L., "AEP Chainette Structure Development," IEEE, Trans. PAS, 104 (10), pp 2844-2851 (Oct 1985).

41. Kempner, L. and Smith, S., "Cross-Rope Transmission Tower-Line Dynamic Analysis," ASCE J. Struc. Engrg., 110 (6), pp 1321-1335 (June 1984).

42. Gary, C., Dufournet, N., and Pourbaix, F., "400-kV Line of Reduced Size," Proc. CIGRE 30th Session, 1, (22-12) (1984).

43. Tsujimoto, K., Yoshioka, O., Okumura, T., Fujii, K., Simojima, K., and Kubokawa, H., "Investigation of Conductor Swinging by Wind and Its Application for Design of Compact Transmission Line," IEEE, Trans. PAS, 101 (11), pp 4361-4369 (Nov 1982).

44. Aihara, K., Sudo, C., Tsukamoto, T., and Nishimura, S., "High-strength and High-fatigue Limit Zinc Galvanized Steel Cord for ACSR," Wire J. Intl., 16 (4), pp 50-54, 57-61 (Apr 1983).

45. Roche, J.B. and Douglass, D.A., "T2 Wind Motion Resistant Conductor," IEEE, Trans. PAS, 104 (10), pp 2879-2887 (Oct 1985).

46. Sakakibara, A., Iisaka, H., Mori, N., Okumura, T., and Kawamura, T., "Development of Low-Wind-Pressure Conductors for Compact Overhead Transmission Line," IEEE, Trans. PAS, 103 (10), pp 3117-3123 (Oct 1984).

47. Bush, R.A., Black, W.Z., Champion, T.C., and Byrd, W.R., "Experimental Verifications of a Real-Time Program for the Determination of Temperature and Sag of Overhead Lines," IEEE, Trans. PAS, 102 (7), pp 2284-2288 (July 1983).

48. Working Group 23.10 of CIGRE, "Technical Basis for Minimal Requirement for Composite Insulators," Electra, (88), pp 84-114 (May 1983) (in English/French).

49. Cherney, E.A., Karady, G., Brown, R.L., Nicholls, J.L., Orbeck, T., and Pragamin, L., "Application of Composite Insulators to Transmission Lines," IEEE, Trans. PAS, 102 (5), pp 1226-1234 (May 1983).

50. Mier-Maza, R., Lanteigne, J., and De Tourreil, C., "Failure Analysis of Synthetic Insulators with Fibreglass Rods Submitted to Mechanical Loads," IEEE, Trans. PAS, 102 (9), pp 3123-3130 (Sept 1983).

51. De Tourreil, C., Roberge, R., and Bourdon, P., "Long-Term Mechanical Properties of High Voltage Composite Insulators," IEEE, Trans. PAS, 104 (10), pp 2918-2921 (Oct 1985).

52. Bianchi, F., Marrone, G., Masetti, C., and Pigini, A., "Recent Laboratory and Field Experiences on Composite Insulators in Italy," L'Energia Elettrica, 60 (1), pp 36-46 (Jan 1983).

53. Fini, G.P., Marrone, G., Gallucci, F., and Pigini, A., "Field Experience and Laboratory Aging Tests on Composite Insulators for Overhead Lines," L'Energia Elettrica, 61 (7-8), pp 310-20 (July-Aug 1984).

54. Meyer, E. and Gartner, J., "Test Method for Evaluation of the Resistance of Fibreglass Rods to Combined Mechanical and Chemical Stress," IEEE, Trans. PAS, 103 (9), pp 2741-2745 (Sept 1984).

55. Lanteigne, J., "Acoustic Emission in Non-Ceramic Insulators," Proc. Ultrasonics Intl. 1983 Conf., Halifax, NS, Canada, pp 54-59 (July 1983).

56. Cherney, E.A., "Cement Growth Failure of Procelain Suspension Insulators," IEEE, Trans. PAS, 102 (8), pp 2765-2774 (Aug 1983).

57. Tsujimoto, K., Sakurada, H., Kato, T., and Okazato, A., "Development and Application of Composite Overhead Ground Wire with Optical Fibers," IEEE, Trans. PAS, 102 (5), pp 1378-1383 (May 1983).

58. Jones, R.H., Alexander, K., and Williams, G., "Pre-Installation Testing and Installation Experience with a Fibre-Optic Covered Shield Wire on a Rochester Gas and Electric Corporation 115 kV Transmission Line," IEEE, Trans. PAS, 103 (8), pp 2076-2080 (Aug 1984).

59. Parker, H.F., Privette, A.D., and Harding, E.P., "Testing of Composite Overhead Ground Wire Containing Optical Fibers," IEEE, Trans. PAS, 104 (6), PP 1564-1570 (June 1985).

60. Pineda, D., Tovar, J., Martinez, F., and Navarro, E., "Use of Optical Cables in Power Transmission Lines," IEEE, Trans. PAS, 102 (4), pp 812-816 (Apr 1983).

BOOK REVIEWS

SOUND AND STRUCTURAL VIBRATION: RADIATION, TRANSMISSION AND RESPONSE

F. Fahy
Academic Press, London
1985, 309 pages

According to the author, this book is meant "to present a unified qualitative and quantitative account of the physical mechanisms and characteristics of linear interaction between audio-frequency vibrational motion in compressible fluids and structures with which they are in contact." As well as a book for the engineering student, Fahy expects the book to be used by those who want to learn and the academician.

Aside from the long sentence above, Frank Fahy writes in a comfortable style; in the qualitative discussions found throughout the text, his aim for those who want to learn is met. In the quantitative treatments, however, the book requires significant effort to stand alone and thus is better used as a textbook and supplemented with notes. The book even has the appearance of a text. There are sample problems at the end of each chapter and answers to selected problems at the end of the book.

The scope and content of this Fahy's work is impressive. Consider a few of the topics treated in the seven chapters: Wave motion in solids and fluids, Sound radiation (an radiation efficiency), The effect of fluid loading on vibration structures, The transmission of sound through partitions (with a very good explanation of coincidence effect), Acoustic excitation of structures, Acoustic coupling, and Numerical analysis (with emphasis on finite elements).

Except for the last chapter, Fahey emphasizes the wave aspects of sound an vibration. I believe this approach is an elegant and classical one to the topic. The author acknowledges that the popular modeling approach to the field, in which energy methods are used, often results in a questionable model, especially as it relates to the interaction of waves with surfaces.

The subject of sound and structural vibration is both complex and difficult. An all-inclusive text would require more than a single volume. To compensate, Professor Fahy has reduced the number of explanations and derivations and concentrated on general concepts and a broad overview of the field. As a result, much of the detail from one equation to another is left to the reader as an exercise. One suggestion not found at the end of a chapter but within the text is to derive the result that half the incident energy is reflected and half transmitted (at a simple support attached to a beam in bending); work done at a cross section by shear forces and bending moments is considered. It is clear that the potential reader needs a strong background in acoustics and mechanics of materials (preferably mathematical elasticity) or plenty of time to study this book on his or her own.

The author often uses "It will be seen .." which I first hoped referred to a discussion later in the text. I came to realize that it would be seen only if the reader made an effort to develop a conclusion.

Sound and Structural Vibration is a demanding book and an excellent one. Although I do not think it is a stand-alone tutorial, it serves a useful role. The book contains current concepts in sound and structural vibration, covers the entire field, and is readable. The references cited are up-to-date and of high quality, and the index is more than adequate. By browsing, the reader can easily be exposed to a new topic or a new approach to this fascinating field.

I am happy to own a copy and recommend this book highly as a text for advanced undergraduates, graduate students in engineering, and as a reference for analytically-minded professionals.

R.J. Peppin
Scantek Inc./ Norwegian Electronics
12140 Parklawn Drive, Suite 465
Rockville, MD 20852

RESEARCH TECHNIQUES IN NONDESTRUCTIVE TESTING — VOL VII

R.S. Sharp, ed.
Academic Press, London
1984, 327 pages, $84.00

Twelve established experts active in the field of Nondestructive Testing (NDT) and related fields

have written the eight chapters that are included in this volume. These authors have provided an excellent reference publication for some relevant research in NDT.

Chapter one discussed computer processing of digitized radiographic or ultrasonic test data. It explains how image processing can be effective in enhancing NDT methods that involve visual inspection of two-dimensional data. Emphasis is given to image processing hardware, image enhancement, and image restoration.

Chapter two is concerned with the quantitative modeling of flaw responses in eddy current testing. The current status of flaw response modeling and inversion in eddy currents is reviewed. This chapter also treats theoretical modeling of eddy currents as an aid in optimizing the design of a test method and formalizing subsequent data analysis.

Chapter three describes mathematical modeling methods for effective ways of nondestructive control using eddy currents. Calculations presented of the magnetic field around specified defects are shown to provide useful ideas about the further development of NDT using eddy currents.

Chapter four outlines the use of a microprocessor-controlled ultrasonic phased array transducer system especially designed for industrial NDT. Topics include the design of array probes, sound field characteristics of phased arrays, instrumentation, examples of electronic beam forming, and defect reconstruction and classification by phased arrays.

Chapter five explains the concept of mode-conversion in ultrasonics as a means for obtaining quantitative information about defects. It provides a review of the present state-of-the-art in mode-conversion NDT and considers current and possible future contributions that these techniques can make in the field of ultrasonic NDT.

Chapter six covers the basic principles of fiber optic sensing techniques and illustrates the principles with detailed descriptions of specific systems relevant to NDT. Temperature probes, acoustic surface wave detection, and displacement sensors are included.

Chapter seven is concerned with reflection acoustic microscopy and its application to NDT. The discussion is restricted to the Quate-type microscope. A reflection scanning acoustic microscope is described, applications of NDT are given, and a review of different techniques for subsurface imaging is presented. Future developments of reflection microscopy with reference to the potential of gas medium and cyrogenic liquid microscopy are also given.

Chapter eight is a very complete review of laser techniques in NDT. Topics are optical scattering, optical sensing, laser-generated probe signals, and NDT applications.

This current volume of Research Techniques in Nondestructive Testing provides the reader with and excellent review of some current research efforts in nondestructive testing. The chapters are well written, informative, and include extensive bibliographies. Scientists, engineers, technologists, and students should find this book valuable.

S.E. Benzley
Professor of Civil Engineering
Brigham Young University
Provo, Utah

SHORT COURSES

1987

JANUARY

VIBRATION DAMPING TECHNOLOGY
Dates: January, 1987
Place: Clearwater, Florida
Objective: Basics of theory and application of viscoelastic and other damping techniques for vibration control. The courses will concentrate on behavior of damping materials and their effect on response of damped systems, linear and nonlinear, and emphasize learning through small group exercises. Attendance will be strictly limited to ensure individual attention.

Contact: David I. Jones, Damping Technology Information Services, Box 565, Centerville Branch USPO, Dayton, OH 45459-9998 - (513) 434-6893.

FEBRUARY

RANDOM VIBRATION IN PERSPECTIVE — AN INTRODUCTION TO RANDOM VIBRATION AND SHOCK, TESTING, MEASUREMENT, ANALYSIS, AND CALIBRATION, WITH EMPHASIS ON STRESS SCREENING
Dates: February 2-6, 1987
Place: Santa Barbara, CA
Dates: March 9-13, 1987
Place: Washington, D.C.
Dates: April 6-19, 1987
Place: Ottawa, Ontario
Dates: June 1-5, 1987
Place: Santa Barbara, CA
Dates: August 17-21, 1987
Place: Santa Barbara, CA
Dates: October 19-23, 1987
Place: Copenhagen, Denmark
Objective: To show the superiority (for most applications) of random over the older sine vibration testing. Topics include resonance, accelerometer selection, fragility, shaker types, fixture design and fabrication, acceleration/power spectral density measurement, analog vs digital controls, environmental stress screening (ESS) of electronics production, acoustic (intense noise) testing, shock measurement and testing. This course will concentrate on equipment and techniques, rather than on mathematics and theory. The 1984 text, "Random Vibration in Perspective," by Tustin and Mercado, will be used.

Contact: Wayne Tustin, 22 East Los Olivos St., Santa Barbara, CA 93105 - (805) 682-7171.

ROTATING MACHINERY VIBRATIONS
Dates: February 9-11, 1987
Place: Orlando, Florida
Objective: This course provides participants with an understanding of the principles and practices of rotating machinery vibrations and the application of these principles to practical problems. Some of the topics to be discussed are: theory of applied vibration engineering applied to rotating machinery; vibrational stresses and component fatigue; engineering instrumentation measurements; test data acquisition and diagnosis; fundamentals of rotor dynamics theory; bearing static and dynamic properties; system analysis; blading-bearing dynamics examples and case histories; rotor balancing theory; balancing of rotors in bearings; rotor signature analysis and diagnosis; and rotor-bearing failure prevention.

Contact: Dr. Ronald L. Eshleman, Director, The Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254.

APPLIED VIBRATION ENGINEERING
Dates: February 9-11, 1987
Place: Orlando, Florida
Objective: This intensive course is designed for specialists, engineers and scientists involved with design against vibration or solving of existing vibration problems. This course provides participants with an understanding of the principles of vibration and the application of these principles to practical problems of vibration reduction or isolation. Some of the topics to be discussed are: fundamentals of vibration engineering; component vibration stresses and fatigue; instrumentation and measurement engineering; test data acquisition and diagnosis; applied spectrum analysis techniques; spectral analysis techniques for preventive maintenance; signal analysis for machinery diagnostics;

random vibrations and processes; spectral density functions; modal analysis using graphic CRT display; damping and stiffness techniques for vibration control; sensor techniques for machinery diagnostics; transient response concepts and test procedures; field application of modal analysis for large systems; several sessions on case histories in vibration engineering; applied vibration engineering state-of-the-art.

Contact: Dr. Ronald L. Eshleman, Director, The Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254

MACHINERY VIBRATION ANALYSIS I
Dates: February 24-27, 1987
Place: San Diego, California
Dates: August 18-21, 1987
Place: Nashville, Tennessee
Dates: November 17-20, 1987
Place: Oak Brook, Illinois
Objective: This course emphasizes the role of vibrations in mechanical equipment instrumentation for vibration measurement, techniques for vibration analysis and control, and vibration correction and criteria. Examples and case histories from actual vibration problems in the petroleum, process, chemical, power, paper, and pharmaceutical industries are used to illustrate techniques. Participants have the opportunity to become familiar with these techniques during the workshops. Lecture topics include: spectrum, time domain, modal, and orbital analysis; determination of natural frequency, resonance, and critical speed; vibration analysis of specific mechanical components, equipment, and equipment trains; identification of machine forces and frequencies; basic rotor dynamics including fluid-film bearing characteristics, instabilities, and response to mass unbalance; vibration correction including balancing; vibration control including isolation and damping of installed equipment; selection and use of instrumentation; equipment evaluation techniques; shop testing; and plant predictive and preventive maintenance. This course will be of interest to plant engineers and technicians who must identify and correct faults in machinery.

Contact: Dr. Ronald L. Eshleman, Director, The Vibration Institute, 101 West 55th Street, Suite 206, Clarendon Hills, IL 60514 - (312) 654-2254.

MARCH

MEASUREMENT SYSTEMS ENGINEERING SHORT COURSE
Dates: March 9-13, 1987
Place: Phoenix, Arizona
Objective: Electrical measurements of mechanical and thermal quantities are presented through the new and unique Unified Approach to the Engineering of Measurement Systems. Test requestors, designers, theoretical analysts, managers, and experimental groups are the audience for which these programs have been designed. Cost-effective, valid data in the field and in the laboratory, are emphasized. Not only how to do that job, but how to tell when it's been done right.

Contact Peter K. Stein, Director, 5602 East Monte Rosa, Phoenix, AZ 85018 - (602) 945-4603 and (602) 947-6333.

MEASUREMENT SYSTEMS DYNAMICS SHORT COURSE
Dates: March 16-20, 1987
Place: Phoenix, Arizona
Objective: Electrical measurements of mechanical and thermal quantities are presented through the new and unique Unified Approach to the Engineering of Measurement Systems. Test requestors, designers, theoretical analysts, managers, and experimental groups are the audience for which these programs have been designed. Cost-effective, valid data in the field and in the laboratory, are emphasized. Not only how to do that job, but how to tell when it's been done right.

Contact Peter K. Stein, Director, 5602 East Monte Rosa, Phoenix, AZ 85018 - (602) 945-4603 and (602) 947-6333.

MAY

ROTOR DYNAMICS & BALANCING
Dates: May 4-8, 1987
Place: Syria, Virginia
Objective: The role of rotor/bearing technology in the design, development and diagnostics of industrial machinery will be elaborated. The fundamentals of rotor dynamics; fluid-film bearings; and measurement, analytical, and computational techniques will be presented. The computation and measurement of critical speeds vibration response, and stability of rotor/bearing systems will be discussed in detail. Finite elements and transfer matrix modeling will be related to computation on mainframe computers, minicomputers, and microprocessors. Modeling and computation of transient rotor behavior and nonlinear fluid-film bearing behavior will be described. Sessions will be devoted to flexible rotor balancing, including

turbogenerator rotors, bow behavior, squeeze-film dampers for turbomachinery, advanced concepts in troubleshooting and instrumentation, and case histories involving the power and petrochemical industries.

Contact: Dr. Ronald L. Eshleman, Director, The Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254

NOVEMBER

VIBRATIONS OF RECIPROCATING MACHINERY AND PIPING

Dates: November 10-13, 1987
Place: Oak Brook, Illinois
Objective: This course on vibrations of reciprocating machinery includes piping and foundations. Equipment that will be addressed includes reciprocating compressors and pumps as well as engines of all types. Engineering problems will be discussed from the point of view of computation and measurement. Basic pulsation theory -- including pulsations in reciprocating compressors and piping systems -- will be described. Acoustic simulation in piping will be reviewed. Calculations of piping vibration and stress will be illustrated with examples and case histories. Torsional vibrations of systems containing engines and pumps, compressors, and generators, including gearboxes and fluid drives, will be covered. Factors that should be considered during the design and analysis of foundations for engines and compressors will be discussed. Practical aspects of the vibrations of reciprocating machinery will be emphasized. Case histories and examples will be presented to illustrate techniques.

Contact: Dr. Ronald L. Eshleman, Director, The Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254

MODAL TESTING OF MACHINES AND STRUCTURES

Dates: November 17-20
Place: Oak Brook, Illinois
Objective: Vibration testing and analysis associated with machines and structures will be discussed in detail. Practical examples will be given to illustrate important concepts. Theory and test philosophy of modal techniques, methods for mobility measurements, methods for analyzing mobility data, mathematical modeling from mobility data, and applications of modal test results will be presented.

Contact: Dr. Ronald L. Eshleman, Director, The Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254

CALL FOR PAPERS

33RD INTERNATIONAL INSTRUMENTATION SYMPOSIUM
May 3-8, 1987
Las Vegas, Nevada

The 33rd International Instrumentation Symposium will convene in Las Vegas. This annual symposium is sponsored jointly by the Aerospace Industries and Test Measurement Divisions of the Instrument Society of America. This symposium has become recognized as the outstanding forum for discussion of new and innovative instrumentation techniques, development and applications. Prospective authors are invited to submit papers in the following interest areas:

MEASUREMENTS: Pressure, Flow, Strain, Motion, Force, Vibration, Thermal, Measurement Uncertainty, Metrology, Blast and Shock

DATA SYSTEMS: Data Acquisition Processing, Real Time Systems, Telemetry Systems, Remote Systems, Computer Applications, Software Design/Development

INSTRUMENTATION SYSTEMS: Flight Test and Avionics, Wind Tunnel, Aerospace, Energy, Transportation, Machinery, Special Test Facilities, Reentry Vehicles/Systems.

ABSTRACTS FROM THE CURRENT LITERATURE

ABSTRACT CONTENTS

AVAILABILITY OF PUBLICATIONS ABSTRACTED

None of the publications are available at SVIC or at the Vibration Institute, except those generated by either organization.

Periodical articles, society papers, and papers presented at conferences may be obtained at the Engineering Societies Library, 345 East 47th Street, New York, NY 10017; or Library of Congress, Washington, D.C., when not available in local or company libraries.

Government reports may be purchased from National Technical Information Service, Springfield, VA 22161. They are identified at the end of bibliographic citation by an NTIS order number with prefixes such as AD, N, NTIS, PB, DE, NUREG, DOE, and ERATL.

Ph.D. dissertations are identified by a DA order number and are available from University Microfilms International, Dissertation Copies, P.O. Box 1764, Ann Arbor, MI 48108.

U.S. patents and patent applications may be ordered by patent or patent application number from Commissioner of Patents, Washington, D.C. 20231.

Chinese publications, identified by a CSTA order number, are available in Chinese or English translation from International Information Service, Ltd., P.O. Box 24683, ABD Post Office, Hong Kong.

Institution of Mechanical Engineers publications are available in U.S.: SAE Customer Service, Dept. 676, 400 Commonwealth Drive, Warrendale, PA 15096, by quoting the SAE-MEP number.

When ordering, the pertinent order number should always be included, not the **DIGEST** abstract number.

A List of Periodicals Scanned is published in issues, 1, 6, and 12.

MECHANICAL SYSTEMS

ROTATING MACHINES

86-2115
Transient Vibrations of a Beam/Mass System Fixed to a Rotating Body
H. Kojima
Gunma Univ., Gunma, Japan
J. Sound Vib., 107 (1), pp 149-154 (May 22, 1986) 7 figs, 4 refs

KEY WORDS: Rotors, Mass-beam systems, Transient vibrations, Flexural vibrations

Transient flexural vibrations of a beam/mass system fixed to a rotating body are investigated. The rotating body is driven so as to have a velocity profile of trapezoidal shape. The governing ordinary differential equations of the beam mass system are derived by use of the extended Galerkin method, and the transient response is obtained by the Laplace transformation. The effects of the flexibility of the beam and the rotational period of the rotating body upon the flexural vibrations are investigated.

86-2116
Vibration of Asymmetric Rotor Supported by Oil Film Bearings
T. Iwatsubo, N. Tsujiuchi, T. Inoue
Kobe Univ., Kobe, Japan
Ingenieur-Archiv., 56 (1), pp 1-15 (1986) 5 figs, 2 tables, 6 refs

KEY WORDS: Flexible rotors, Oil film bearings, Stability, Unbalance mass response

This paper deals with the stability problems of an asymmetric flexible rotor supported by asymmetric bearings, in which the bearing is modified to the stiffness and damping forces with coupling terms in order to represent the oil film bearing character. The equation of motion is derived, then analyzed by translating the coordinate system to a new orthogonal one using complex eigenvalues. The stability and unbalance response is analyzed using an asymptotic method.

86-2117
Modes for Deformable Periodic Cyclic Symmetric Systems Driven in Uniform Rotation by a Flexible Shaft
S. Dubigeon, J.C. Michon
Ecole Nationale Superieure de Mecanique, Nantes, France
J. Sound Vib., 106 (1), pp 53-70 (Apr 8, 1986) 8 figs, 15 refs

KEY WORDS: Shafts, Flexible rotors, Periodic structures, Modal analysis

An analysis is presented of the configurations which periodic cyclic symmetric structures can take when connected together in a repetitive pattern. One extremity is connected to a hub with a large, inherent, set rotation; this hub is then attached to a rotating flexible shaft. The modal analysis set out in this paper results in three uncoupled families of modes, each with its own gyroscopic coupling. The method is demonstrated on a relatively simple model.

86-2118
Torsional Modal Analysis of Free-Free Shafts Carrying an Arbitrarily Located Lumped Inertia
N.D. Ebrahimi
The Univ. of New Mexico, Albuquerque, NM
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol.1 pp 196-201, 5 figs, 9 refs

KEY WORDS: Shafts, Modal analysis, Torsional Vibration, Inertial forces

The torsional vibration of a shaft with free ends is analyzed. The shaft can carry an arbitrarily located, rigid lumped inertia. In the analysis, which considers both free and forced responses, the partial differential equations that govern the dynamics of the assembly are written. The method of separation of variables is applied to obtain the ordinary differential equations that will be used to derive transcendental equations for the natural frequencies. The exact expressions for the natural mode shapes and the amplitude of the forced vibration of the shaft are also derived as well as its transmissibility ratio. The results are summarized in dimensionless plots. Designers can use these plots as tools for predicting the natural frequencies and forced responses in practical applications.

86-2119
Dynamic Stability of the Rotating Shaft Made of Boltzmann Viscoelastic Solid
W. Zhang, F.H. Ling
Fudan Univ., Shanghai, Peoples Rep. of China
J. Appl. Mech.Trans. ASME, 53 (2), pp 424-429 (June 1986) 5 figs, 13 refs

KEY WORDS: Shafts, Viscoelastic properties Stability

A general theory is developed for studying the dynamic stability of high-speed nonuniform rotating shafts made of a Boltzmann viscoelastic solid. The equation of motion of the shaft is deduced. The stability criteria are derived by using this equation. The unstable regions for a nonhomogeneous viscoelastic shaft are worked out numerically. Analytical formulas are also given for determining the planar deflection of the shaft and its inclined angle due to a planar static load. The conclusions for special cases given in the literature are all covered by the results.

86-2120
Modeling of Multi-Rotor Torsional Vibrations in Rotating Machinery Using Substructuring
F.R. Soares
Rockwell Intl. Corp., Downey, CA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1 pp 360-370, 15 figs, 3 tables, 7 refs

KEY WORDS: Mode shapes, Substructuring methods, Torsional vibrations, Rotating machinery, Finite element technique

Component mode synthesis has been widely used to predict general multi-rotor torsional behavior. The usual practice in a multi-geared system is to replace the branched system with an equivalent linear system on a single drive/shafting which when analyzed results in inadequate predictions. The approach described in this paper seeks to exploit the vastly successful techniques of the general finite-element method (FEM) as applied in the field of structural dynamics. In combination with FEM, the distributed mass model's advantages over the lumped mass model are demonstrated. The work specifically described is an outcome of a NASA-Lewis sponsored research grant on Rotodynamics. The development of a finite-element model for torsional analysis of multi-rotor systems and the subsequent preparation of a STAND-ALONE TORSIONAL VIBRATIONS (STORV) computer code are the results of this research.

86-2121
Transverse Vibrations of a Rotating Uniform Cantilever Beam with Tip Mass as Predicted by Using Beam Characteristic Orthogonal Polynomials in the Rayleigh-Ritz Method
R.B Bhat
Concordia Univ., Montreal, Quebec, Canada
J. Sound Vib., 105 (2), pp 199-210 (Mar 8, 1986) 12 figs, 3 tables, 18 refs

KEY WORDS: Rotating structures, Mass-beam systems, Cantilever beams, Flexural vibrations, Rayleigh-Ritz method

Natural frequencies and mode shapes of a rotating uniform cantilever beam with a tip mass are studied by using beam characteristic orthogonal polynomials in the Rayleigh-Ritz method. The set of orthogonal polynomials which satisfy the geometrical boundary conditions are generated by using the Gram-Schmidt process. The results are compared with those obtained by the Myklestad method, the extended Galerkin method and finite element methods. The variation of natural frequencies with the speed of rotation is plotted for several parameter combinations such as setting angle, tip mass, moment of inertia of tip mass, etc. Mode shapes at different rotational speeds are also plotted. Use of orthogonal polynomials for the deflection shapes enables the computation of higher natural frequencies of any order to be accomplished without facing any numerical difficulties, which is not the case when arbitrary polynomial expressions are used.

86-2122
Vibration of Finite Length, Rotating Cylindrical Shells
T. Saito, M. Endo
Tokyo Inst. of Tech., Ookayama, Meguro-ku, Tokyo, Japan
J. Sound Vib., 107 (1), pp 17-28 (May 22, 1986) 5 figs, 13 refs

KEY WORDS: Rotating structures, Cylindrical shells, Galerkin method

The Flugge type basic equations for a finite length, rotating cylindrical shell, including the effect of the initial tensions due to the rotation, are employed, and by Galerkin's method frequency analyses of traveling waves are presented for three kinds of boundary conditions--both ends clamped, simply supported without axial constraint, and simply supported with axial constraint. In all these cases it is found that the dependence of the frequencies upon the rotational speed is insignificantly affected by the boundary conditions, and thus can be represented by the simple relation for a thin rotating ring, provided that the frequencies and rotating speeds are normalized by the natural frequencies of a nonrotating cylindrical shell.

86-2123
The Effects of Tip Clearance on the Noise of Low Pressure Axial and Mixed Flow Fans
T. Fukano, Y. Takamatsu

Kyushi Univ., Fukuoka, Japan
J. Sound Vib., 105(2), pp 291-308 (Mar 8, 1986), 19 figs, 2 tables, 24 refs

KEY WORDS: Fan noise, Ducts, Clearance effects

Results are presented of a systematic experimental investigation of the effects of tip clearance on both noise and performance of four commercially representative fans (three low presssure axial flow and one mixed flow) in a circular duct, both with and without coincidence of the fan and duct axes (fan/duct eccentricity). It is shown that with eccentricity significant pure tone noise is generated due to blade tip/duct wall interaction, with a plane wave mode component. Reducing tip clearance both improves performance and reduces noise, not only at the maximum efficiency operating point but also in an appreciable low flow rate operating region. With tip clearances small enough to optimize performance and minimize noise, fan/duct eccentricity must be kept to a very small value, implying strict precautions in fan and duct manufacture, installation and service conditions.

86-2124
The Statistical Variation of Modal Parameters Within Production Units
J.P. Lauffer
Sandia National Labs., Albuquerque, NM
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 700-707, 15 figs, 2 tables, 7 refs

KEY WORDS: Wind turbines, Natural frequencies, Damping coefficients, Experimental data, Statistical analysis

Verifying the accuracy of a finite element model typically entails comparing the predicted modal frequencies to the results of an experimental modal survey. An inherent assumption is that the tested structure is representative of all production units. To evaluate this assumption, 20 wind turbines from a single production run were tested to determine the statistical variation of their modal frequencies and damping factors. For wind turbines it is particularly important to know the variation of the modal frequencies, as they must be known within 2% for current design practices. This report evaluates the stringency of this design requirement in light of the variation in modal parameters between production units.

86-2125
Complex Modal Analysis in Turbine Design
H.L. Olausson, B.J. Torby
ASEA STAL, Finspong, Sweden
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 189-195, 2 figs, 9 refs

KEY WORDS: Modal analysis, Turbines, Design techniques, Component mode synthesis

A complex modal analysis method is presented for studying the behavior of a turbine near its design speed. Gyroscopic moments, as well as nonsymmetric bearing effects, are accounted for in the modal calculations. The complex mode shapes that are found here more accurately describe steady state orbital motion. Transient motion, induced by some disturbance from a dynamic equilibrium state, is best formulated through a series expansion of the complex normal coordinate terms associated with these mode shapes. The ensuing equations of motion can then be integrated and the solution brought back to the problem's original generalized coordinates. Since in normal coordinate description no distinction can be made between modes obtained mathematically and those found experimentally, the paper also describes how the latter mode shapes can easily be coupled to the system equation when they are considered as substructure component-modes. This use of component-mode synthesis allows the turbine model to incorporate several rotors turning at different speeds, and even torsional motion.

86-2126
SSME Structural Dynamic Model Development, Phase 2
M.J. Foley, V.L. Wilson
Lockheed Missiles and Space Co., Inc., Huntsville, AL
Rept. No. NASA-CR178708, 234 pp (Nov 1985) N86-20496/3/GAR

KEY WORDS: Pumps, Mathematical models

A set of test correlated mathematical models of the SSME high pressure oxygen turbopump housing and rotor assembly was produced. New analysis methods within the EISI/EAL and SPAR systems were investigated and runstreams for future use were developed. The LOX pump models have undergone extensive modification since the first phase of this effort was completed. A description of the new rotor math model is presented. The pump housing model which was continually modified is documented along with measured test results. Many of the

more advanced features of the EAL/SPAR finite element analysis system were exercised. A new tool was developed that allows an automated analysis of a disjoint structure in terms of its component modes.

86-2127

Applications of Modal Techniques to Noise Control of Hermetic Refrigeration Compressors

S.M. Price, R.J. Bernhard
Purdue University, West Lafayette, IN

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 515-519, 10 figs, 1 table, 7 refs

KEY WORDS: Compressors, Modal analysis, Noise reduction

That there exists interaction between vibration and structure-borne or structurally radiated sound is generally recognized. However, it is often difficult to predict the complex interactions between excitation forces, structural responses and the generation of sound. This paper discusses such interaction especially in light of modal characterizations of the structural vibrations. A case history of application of these techniques to control of noise emissions from a hermetic reciprocating compressor is also discussed.

86-2128

Role of Shocks in Transonic/Supersonic Compressor Rotor Flutter

O.O. Bendiksen
Princeton Univ., Princeton, NJ

AIAA J., 24 (7), pp 1179-1185 (July 1986) 10 figs, 24 refs

KEY WORDS: Compressors, Flutter, Cascades, Shock excitation

An investigation of the influence of shock motion on flutter of rotors and cascades is presented. The present paper illustrates how a perturbation scheme can be used to calculate the nonlinear effects due to thickness, camber, and incidence to second order in a perturbation parameter. An approximate theory is also given, that accounts for the first-order quasisteady effects of shock motion and also allows experimentally determined shock structures and parameters to be used. The unsteady aerodynamic forces resulting from shock movements are shown to have a pronounced effect on the flutter boundaries of cascades representative of large fan rotors. Both stabilizing and destabilizing effects are observed, depending on interblade phase angle and shock structure. At low reduced frequencies, the shock-induced loads can destabilize bending oscillations sufficiently to cause single-degree-of-freedom bending flutter. It is also possible to explain the stabilizing effect of the back pressure on supersonic rotor flutter, as observed experimentally.

METAL WORKING AND FORMING

86-2129

A Dynamic Relaxation Finite-Element Method For Metal Forming Processes

Pei Chi Chou, Longwu Wu
Drexel Univ., Philadelphia, PA

Int. J. Mech. Sci., 28 (4), pp 231-250 (1986) 12 figs, 2 tables, 44 refs

KEY WORDS: Metal workings, Finite element technique, Dynamic relaxation, Computer programs, Damping coefficients

Conventional finite-element methods (FEM) used in metal forming processes usually use the stiffness matrix approach. In this paper, a somewhat unconventional FEM program, which involves the modification of a dynamic finite-element program, is used to solve static metal forming problems. The modification is by adding artificial damping terms to a dynamic program DEFEL, which makes the approach equivalent to the dynamic relaxation (DR) method. The basic dynamic program DEFEL is described and the theory and equations of DR as applied to DEFEL are presented. Example problems are included and results are compared with those available from other sources. Impact on a solid cylinder is calculated by the same program, showing that both dynamic and static solutions can be obtained with one computer program.

86-2130

Design of Machine-Tools: The Random Response Calculations of Machine Tools Subjected to Stochastic Excitations Using Dynamic Condensation Technique

A.M. Sharan, V.R. Reddy
Memorial Univ. of Newfoundland, St. Johns's Newfoundland, Canada

J. Mech., Transm., Autom. in Des., Trans. ASME, 108 (2), pp 145-151 (June 1986), 3 figs, 3 tables, 10 refs

KEY WORDS: Machine tools, Response spectral density Stochastic processes, Dynamic condensation technique, Design techniques

The response spectral density is an important parameter which should be examined by a machine-tool analyst. A new approach for the calculation of response spectral density for a linear stationary random multi-degree-of-freedom system is presented. This method is based on condensing the system matrices and introducing a set of auxiliary variables. The response spectral density matrix obtained by using this new approach contains the spectral densities and the cross-spectral densities of the master degrees-of-freedom chosen. The new method requires significantly less computation time, as compared to conventional methods, for calculating response spectral densities associated with the selected number of degrees of freedom. To compare the computation time, three numerical examples are presented.

86-2131
Application of Modal Analysis Methodology to Study Machining Process Stability of Machine Tools
W. Gangfu, P. Zemin
Tianjin Univ., Tianjin, China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 209-216, 4 figs, 6 refs

KEY WORDS: Machine tools, Modal analysis, Cutting, Stability

A new approach to studying the machining stability of machine tools is developed. A distinguishing feature of this approach is to combine the modal analysis of the machine tool structure with investigation of the cutting process with respect to ground inertial reference system. The dynamic cutting process due to regenerative effect is analyzed by the complex modal theory for a closed loop dynamic system of machine tools including both the machining process and machine tool structure. A criterion for threshold condition of regenerative chatter described by modal parameters of the machine tool structure and dynamic cutting force is proposed.

86-2132
Vibration and Chatter Analysis of an NC Lathe
J.M. Lee, H.S. Lee, D.C. Han, S.Y. Lee
Seoul National Univ., Seoul, Korea
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 781-786, 16 figs, 3 tables, 16 refs

KEY WORDS: Machine tools, Chatter, Lathes, Finite element technique, Modal analysis

In order to investigate the influence of the structural dynamics of machine tools on chatter, dynamic characteristics of a newly fabricated NC lathe are analyzed using the finite element method. The bed, the base body and the spindle-bearing system of the lathe are analyzed separately and then total dynamic characteristics are obtained by the component mode synthesis method. Chatter experiments were performed with tapered MTIRA workpieces. With this experimental set-up, both the direct cutting tests and the excitation test can be performed. Component mode synthesis with the direct cutting/excitation test is proposed as the powerful tool for design modification to improve dynamic performance of machine tools.

86-2133
Application of Impulse Excitation Method to Machine Tool Modal Analysis
Qinghong Sun, Si Zhang, Shaocheng Huo
Nanjing Inst. of Tech., Nanjing, China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol.1, pp 606-610, 6 figs, 3 tables, 2 refs

KEY WORDS: Machine tools, Modal analysis, Fourier analysis

Based on the complex modal theory, some problems arising in machine tool modal analysis by impulse excitation are examined. A C336K-1 turret lathe is used in this case. Through the modal dynamic display from a Fourier analysis system (referring to video tape recording), 13 order vibration modes of the whole machine tool and 13 order separate vibration modes of 4 main parts (headstock, turret, bed and carriage) are vividly shown. The problems of the machine tool structure are clearly revealed.

86-2134
The Machine Tool Rigidity Factor in Modelling a Computerised Machinability Data Base System
M. Rahman, V.C. Venkatesh
National Univ. of Singapore, Kent Ridge, Singapore
Intl. Modal Analysis Conf., Proc. of the 4th Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 532-535, 2 figs, 10 refs

KEY WORDS: Modal analysis, Machine tools

Modal analysis is a powerful tool in machine tool rigidity studies. The results of these studies have rarely been considered by research workers when modeling mathematically the extended Taylor tool life equation. The rigidity factor is

used in these equations and the computerized machinability data base systems (CMDBS) contains this novel concept. The optimum cutting data obtained thereby for turning operations was found to be very reasonable. The use of a fully comprehensive CMDBS in CNC machine tools is one of the essential steps towards the goal of computer integrated manufacturing.

86-2135
The Dynamic Optimum Design for the Surface Grinding Machine Structure
Z. Weizhong
Shanghai Engineering Technical Univ., Shanghai, China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 171-176, 3 figs, 4 tables, 6 refs

KEY WORDS: Experimental modal analysis, Grinding machinery, Optimum design

The method of dynamic optimum design for a surface grinding machine structure is described. The machine is represented by a lumped-parameter model of a vibratory system with 11 degrees-of-freedom. Based on computation of modal flexibility and energy distribution, the dynamically weakest part of this machine -- the wheel head system -- is found. Several structural parameters of the wheel head system are taken as design variables. The results of optimization show that the cantilever arm of the wheel and distance between the bearings have an optimum correlation, and regulation of some modal damping ratios is important.

MATERIALS HANDLING EQUIPMENT

86-2136
A Comparison of Analysis Techniques for Offshore Platform Cranes
J.A.D. Balfour
Heriot-Watt Univ., Edinburgh, UK
Structural Engineer, 63B (2), pp 21-26 (June 1985) 6 figs, 1 table, 18 refs

KEY WORDS: Cranes, Drilling platforms, Offshore structures, Modal superposition method, Direct integration technique

This paper compares the efficiency of mode superposition and direct integration methods for the dynamic analysis of offshore platform cranes. Newmark's method and the central difference method, which integrate the equations of motion directly, are compared with the method of mode superposition on the basis of computer time, computer storage, and program complexity. Programming techniques to improve the efficiency of the different algorithms are described. Results are presented that show the central difference method to be uneconomic in comparison with the other two methods. The method of mode superposition, while requiring marginally more computer storage, is shown to offer substantial savings in computer time over Newmark's method.

STRUCTURAL SYSTEMS

BRIDGES

86-2137
Modal Testing of the Tjorn Bridge
S. Ohlsson
Chalmers Univ. of Technology, Goteborg, Sweden
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 599-605, 13 figs, 2 refs

KEY WORDS: Bridges, Experimental modal analysis, Cable stayed structures

The Tjorn bridge is a cable stayed steel box girder bridge with a 366m span. Two kinds of field tests were carried out before it was opened to traffic: a forced vibration test (broad-band) and a free decay test (fundamental mode). The forced vibration test was conducted using swept sine excitation from an especially constructed device acting between the bridge deck and a gravity mass and modal analysis was performed. The free decay test was initiated by sudden release of the bridge from a preloaded condition. The resulting free vibration showed that the damping had a strong amplitude dependence.

BUILDINGS

86-2138
Calculation of Airborne and Impact Sound Insulation Between Dwellings
E. Gerretsen
Institute of Applied Physics, Delft, Netherlands
Appl. Acoust., 19 (4), pp 245-264 (1986) 13 figs, 16 refs

KEY WORDS: Buildings, Acoustic insulation

A model for the calculation of weighted airborne sound insulation between dwellings has been extended to include octave band calculations and impact sound insulation. These calculations are based largely on the same input data as for airborne sound. A new quantity, however, is the floor admittance. For homogeneous floors an existing model for the calculation of the admittance could be applied. For typical floor constructions consisting of concrete beams and plates a model for the admittance has been developed, based on admittance measurements in situ. Some examples are given of calculated and measured airborne and impact sound insulation.

86-2139
Study of Stress in Truss Wind Bracing by the Finite Element Method
T. Kamga, K. Fomo
Ecole National Superieure Polytechnique, Cameroon, Africa
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 297-302, 4 figs, 5 refs

KEY WORDS: Modal analysis, Multistory buildings, Wind-induced excitation, Finite element technique

The explosive expansion of the finite element method finds many applications in the domain of building, especially in analysis of the constraint due to external solicitation. The finite element method is used to calculate the displacement of a high rise building under wind solicitation. A sixteen degrees-of-freedom element is employed and results obtained are systematic and satisfactory.

86-2140
Simplified Seismic Analysis of Piping or Equipment Mounted on Two Points of Multistory Structure
R. Villaverde
Univ. of California, Irvine, CA
Nucl. Engrg. Des., 92 (1), pp 37-50 (Mar 1986) 6 figs, 3 tables, 19 refs

KEY WORDS: Multistory buildings, Equipment-structure interaction, Seismic response

A simplified procedure is presented to calculate the maximum earthquake response of light mechanical or electrical equipment supported at two arbitrary points of a building structure. The procedure is derived on the basis of the application of the response spectrum method to a combined structure-equipment system, but, in an effort to avoid the complications of such an approach, it is formulated in terms of the dynamic characteristics of the two independent components. It fully takes into account the interaction between the two subsystems, and avoids the generation of floor response spectra and the need to consider two different support excitations. The formulation is attained by using Hurty's component mode synthesis technique and Rayleigh's principle. Linear systems with classical modes of vibration and small structure to equipment mass ratios are considered. The simplicity of the method is demonstrated by a numerical example, and its accuracy verified by a comparative study.

86-2141
An Evaluation of Equivalent Linear Models for Modal Analysis of Nonlinear Systems Subjected to Earthquakes
M. Saiidi, E.A. Maragakis
Univ. of Nevada, Reno, NV
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 137-142, 4 figs, 1 table, 6 refs

KEY WORDS: Modal analysis, Seismic response, Multistory buildings, Reinforced concrete, Nonlinear systems

This paper summarizes a study to evaluate the validity of using modified dynamic properties of a structure in conjunction with elastic response spectra for the performance of modal analysis when the structural response is in the nonlinear range. To evaluate this technique, two small-scale nine story reinforced concrete structures were excited by six widely known earthquake records all of which caused significant yielding to the structures. In each case, the maximum displacement of each structure, found from its response history, was compared with the corresponding response maximum spectral displacement, which was estimated based on an effective period. The comparison demonstrated clearly that the results from the modal analysis, using an effective period, do not generally agree with the results from the more realistic response history analysis. The use of the elastic response spectra, when nonlinear response is predominant, was found to yield results of a nonuniform trend, sometimes overestimating and sometimes underestimating the structural response.

UNDERGROUND STRUCTURES

86-2142
Seismic Damage Behavior of Buried Lifeline Systems During Recent Severe Earthquakes in U.S., China, and Other Countries

L.R. Wang, S. Shao-ping, S. Shije
Old Dominion Univ., Norfolk, VA
Rept. No. ODU/Lee-02, NSF/ENG-85059, 80 pp (Dec 1985) PB86-187093/GAR

KEY WORDS: Underground structures, Lifeline systems, Seismic response, Earthquake damage

The report is the product of a joint research effort by scientists in the United States and the People's Republic of China. The report discusses damage to buried lifeline systems, resulting from four recent severe earthquakes. Common types of damage to buried pipeline and factors influencing them are listed.

86-2143
Thermal Analysis of Buried Piping
P.M. Joodi
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 130-136, 2 figs, 2 tables, 5 refs

KEY WORDS: Underground structures, Tubes, Nuclear reactor components, Soil-structure interaction, Seismic response

The growing use of tubular structures in nuclear reactor facilities such as pipes, conduits and ducts that are buried underground, required more detailed stress analysis to demonstrate structural integrity as required by Section III. of the Boiler Pressure Vessel Code and other applicable industry codes. Thermal behavior of pipe and soil interference can be conservatively evaluated by implementing the thermal characteristics and properties of the pipe into the expressions which are made for the seismic analysis of buried piping. This paper presents procedures to evaluate the different pipe/soil parameters to be applied in those expressions, repeats and explains these equations from designers' perspectives, and suggests an approach to combine various pipe stresses in check against ASME Boiler and Pressure Vessel Code Section III. The analysis assumes that the soil is linearly elastic and homogeneous and the structure is a straight slender solid or hollow beam with a uniform, symmetrical cross section that satisfies the conditions of the elementary theory of beams on elastic foundations.

HARBORS AND DAMS

86-2144
Effect of Sediment on Earthquake-Induced Reservoir Hydrodynamic Response
A.H.-D. Cheng
Univ. of Delaware, Newark, DE
ASCE J. Engrg. Mech. 112 (7), pp 654-665 (July 1986) 4 figs, 7 refs

KEY WORDS: Dams, Seismic excitation

In a typical reservoir a sediment layer of considerable depth may be deposited on top of exposed bedrock foundation. The effect of sediment on the dissipation and damping of earthquake induced hydrodynamic waves has been ignored in earlier studies of dam-reservoir-foundation system. The present work models the sediment as a poroelastic material. For vertical excitations, analytical solutions are sought with the aid of computer algebra (MACSYMA). As a result, the bottom damping coefficients are explicitly expressed as functions of material properties of earthquake frequency. For a modest amount of sediment and slight desaturation of pore water, significant changes in the hydrodynamic response curves are observed.

POWER PLANTS

86-2145
Nonlinear Dynamics and Stability of Boiling Water Reactors: Part 1 —Qualitative Analysis
J. March-Leuba, D.G. Cacuci, R.B. Perez
Univ. of Tennessee, Knoxville, Tennessee
Nucl. Sci. Engrg., 93, pp 111-123 (June 1986) 14 figs, 24 refs

KEY WORDS: Nuclear reactors, Stochastic processes, Nonlinear response, Limit cycle analysis

A phenomenological model has been developed to simulate the qualitative behavior of boiling water reactors (BWRs) in the nonlinear regime under deterministic and stochastic excitations. After the linear stability threshold is crossed, limit cycle oscillations appear due to interactions between two unstable equilibrium points and the phase-space trajectories. The limit cycle becomes unstable when the feedback gain exceeds a certain critical value. Subsequent limit cycle instabilities produce a cascade of period-doubling bifurcations that lead to aperiodic pulsed behavior. Under stochastic excitations, BWRs exhibit a single characteristic resonance in the linear regime. By contrast, this work shows that harmonics of this characteristic frequency appear in the nonlinear regime. This work also demonstrates that amplitudes of the limit cycle oscillations do not depend on the variance of the stochastic excitation and remain bounded at all times.

86-2146
Nonlinear Dynamics and Stability of Boiling Water Reactors: Part 2 — Quantitative Analysis
J. March-Leuba, D.G. Cacuci, R.B. Perez
Univ. of Tennessee, Knoxville, Tennessee
Nucl. Sci. Engrg., 93, pp 124-136 (June 1986) 6 figs, 9 tables, 13 refs

KEY WORDS: Nuclear reactors, Stochastic processes, Nonlinear response, Limit cycle analysis

A physical model of nonlinear boiling water reactor (BWR) dynamics has been developed and employed to calculate the amplitude of limit cycle oscillations and their effects on fuel integrity over a wide range of operating conditions in the Vermont Yankee reactor. These calculations have confirmed that, beyond the threshold for linear stability, the reactor's state variables undergo limit cycle oscillations. This work shows that the amplitudes of these oscillations are very sensitive to changes in operating conditions and are not restricted to small magnitudes as observed in previous stability tests. Consequently, large-amplitude limit cycle oscillations become a possible scenario for BWR operation at low-flow conditions. The effects on fuel integrity of such large-amplitude oscillations have been studied in detail. It has been shown that limit cycles that oscillate with frequencies higher than 0.25 Hz and that reach the high-power safety scram level of 120% are not likely to compromise fuel integrity.

86-2147
Seismic Qualification of Motor Control Centers Based on Experimental Modal Analysis
C.D. Sellers
Cygna Energy Services, San Francisco, CA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 143-150, 15 figs, 3 tables, 7 refs

KEY WORDS: Nuclear power plants, Experimental modal analysis, Seismic response

Safety related equipment in nuclear power plants requires seismic qualification. Motor control centers (MCCs) are large cabinets housing electrical components required to power and control motors throughout the plant. The MCC cabinet requires structural qualification and the components require operability qualification. MCCs are numerous in power plants and present unique qualification difficulties. The reports of type testing previously performed by the manufacturer on the MCCs are insufficient to support current seismic equipment qualification requirements due to MCC installation, recent modifications, and the lack of component specific required response spectra. Experimental modal analysis was used to eliminate the need for expensive finite element analysis. The MCC cabinets were qualified by hand calculations using a modified static coefficient method. Required seismic response spectra were generated for components located within the cabinets using mode superposition time-history analysis.

OFF-SHORE STRUCTURES

86-2148
Effect of the Second-Order Potential in the Slow-Drift Oscillation of a Floating Structure in Irregular Waves
J.A.P. Aranha, C.P. Pesce
Cidade Univ., São Paulo, Brazil
J. Ship Res., 30 (2), pp 103-122 (June 1986) 6 figs, 10 refs

KEY WORDS: Floating structures, Moorings, Oscillation, Water waves

The slow-drift phenomenon is important when the waves are irregular and the sea spectrum has a relatively narrow band. An expression is derived for the low-frequency force due to the second-order potential. This expression is the lading-order contribution in the wave spectrum bandwidth and can be exactly determined without computing the second-order potential. It is shown that this effect is of importance when the water depth is relatively shallow or the typical wave period relatively long.

VEHICLE SYSTEMS

GROUND VEHICLES

86-2149
Evolutionary (Frequency/Time) Spectral Analysis of the Response of Vehicles Moving on Rough Ground by Using "Covariance Equivalent" Modelling
R.F. Harrison, J.K. Hammond
Oxford Univ., Oxford, England
J. Sound. Vib., 107 (1), pp 29-38 (May 22, 1986) 4 figs, 11 refs

KEY WORDS: Ground vehicles, Road roughness, Noise generation, Spectrum analysis

In a number of physical problems such as the motion of vehicles traveling over rough ground or the noise emanating from a moving source, nonstationarity is induced by a nonlinear time dilation (due to velocity variations or Doppler effects) of the source or excitation process so that the resulting process is frequency modulated. This is true even if the underlying process is homogeneous in another domain. It has not been possible to apply the frequency/time analysis due to Priestly to this class of problem but, by introducing the concept termed "covariance equivalence" by the authors, this method can be seen to apply. An example of a vehicle moving with variable velocity on a rough surface is considered.

SHIPS

86-2150
The Water Column Oscillation in a Duct Between Two Half Ship Section Barriers
B.S. Lee, A.H. Day
Univ. of Strathclyde, Glasgow, Scotland
J. Ship Res., 30 (2), pp 127-133 (June 1986) 8 figs, 11 refs

KEY WORDS: Ships, Ducts, Water waves, Wave energy

The oscillation of a water column in a duct between two half ship section barriers is relevant to several practical applications, notably wave energy devices and moonpools for the launch/retrieval of subsea units from diving support vessels. The oscillation is solved for the case where the barriers are space fixed, and the method used is then extended to include effects due to the heave motion of the barriers. Results obtained in the form of response amplitude operators indicate that the water column oscillation demonstrated a distinct peak response, and that the key parameter controlling this response is the ratio of duct width to barrier draft.

86-2151
Nonlinear Stability Analysis of Ship Towed by Elastic Rope
M.M. Bernitsas, M.S. Kekridis
Univ. of Michigan, Ann Arbor, MI
J. Ship Res., 30 (2), pp 136-146 (June 1986) 109 figs, 3 tables, 18 refs

KEY WORDS: Ships, Towed systems

The course stability of a towed vessel is traditionally assessed using local linear analysis of a time-independent system of a ship towed by an inelastic towline. In this work a method is developed for studying the global stability of a nonlinear time-dependent model of the horizontal plane motions of a ship towed by a nonlinear elastic rope. First, the critical points of the corresponding autonomous system are found in the phase space and their nature is determined by local analysis. Then the global behavior of the trajectories in the phase space is predicted on the basis of the local analysis results. The results of the stability analysis are verified by comparison with the solution of the model by simulation. A barge, a tanker and a Mariner, with markedly different course stability characteristics, towed by two different elastic ropes are used to illustrate the method.

AIRCRAFT

86-2152
Modal Analysis of a Typical Fighter Aircraft Using Transient Testing Technique
R. Balasubramaniam, D.S. Ramakrishna, P.S. Vijayakumar
Natl. Aeronautical Lab., Bangalore, India
Rept. No. NAL-TM-ST-8517, 30 pp (Dec 1985) N86-20385/8/GAR

KEY WORDS: Aircraft, Experimental modal analysis, Transient excitation, Experimental data

The dynamic performance of individual structural components and the whole aircraft are evaluated. The dynamic properties of the aircraft and its components are analyzed. One hundred and thirty nine locations for transient imputs are chosen using an instrumented hammar and on-line data reduction for modal properties. Results from up to six modes of the natural frequency modal mass and stiffness and damping tests are presented. The test set-up, choice of locations for excitations, and actual test procedures are outlined. The advantages of sweep-sine, step relation random and transient test methods on aircraft structures are discussed.

86-2153
Frequency-Domain Application of Gauss-Newton Method to Extract Aircraft Longitudinal Parameters
S.C. Raisinghani, A.K. Goel
Indian Institute of Technology, Kanpur, India
Aeronaut J., 90 (1), pp 27-34 (Jan 1986) 4 figs, 5 tables, 16 refs

KEY WORDS: Aircraft, Modal analysis, Minimization technique, Gauss-Newton method, Finite difference technique

A simplified output error method based on the Gauss-Newton minimization technique is formulated in the frequency-domain and its application demonstrated for extraction of aircraft longitudinal parameters from simulated flight data. A study is carried out to show the effects on the accuracy of estimated parameters due to use of different input forms to generate the flight data, using different initial values to start the algorithm, presence of measurement noise in the flight data and fixing some weak parameters at a priori values. Advantages of the frequency-domain approach versus the time-domain approach are pointed out by analyzing the same flight data in these two domains. It is shown that frequency-domain approach is better equipped to analyze noisy-data and can yield better estimates at reduced computational time.

86-2154
Experimental and Theoretical Modal Analysis on Two Versions of a Twin Turboprop General Aviation Aircraft
L. Lecce, F. Marulo
Univ. of Naples, Naples, Italy
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 303-310, 14 figs, 4 tables, 16 refs

KEY WORDS: Linking analysis and test, Aircraft, Experimental modal analysis

This paper focuses on modal test and analyses performed on two versions of twin turboprop general aviation aircraft. Stretching of the fuselage and under-carriage layout are significant differences between the versions. For both aircraft versions theoretical modal analysis was performed. The results obtained both from the tests and the computations show interesting comparisons.

86-2155
Noise Control Characteristics of Synchrophasing, Part 1: Analytical Investigation
C.R. Fuller
Virginia Polytechnic Institute and State Univ., Blacksburg, VA
AIAA J., 24 (7), pp 1063-1068 (July 1986) 11 figs, 6 refs

KEY WORDS: Aircraft, Noise reduction, Synchrophasing method

The noise control characteristics of synchrophasing are investigated using a simplified model of an aircraft fuselage. The analysis presented includes directivity effects of the noise sources and solves the coupled motion between the interior and exterior acoustic fields and the shell vibrational response in closed form. The variation in sound pressure level at various locations inside the shell is studied for various synchrophase angles and the shell vibrational response and input power flow to uncover the principal mechanisms behind the transmission phenomena.

86-2156
Acoustic Guide for Noise Transmission Testing of Aircraft
R. Vaicaitis
NASA, Langley Research Center, Hampton VA
U.S. Patent Appl-6-751 695/GAR, 13 pp (July 1985)

KEY WORDS: Aircraft, Noise transmission, Measurement techniques, Measuring instrumentation

Selective testing of aircraft or other vehicular components without requiring disassembly of the vehicle or components was accomplished by using a portable guide apparatus. The device consists of a broadband noise source, a guide to direct the acoustic energy, soft sealing insulation to seal the guide to the noise source and to the vehicle component, and noise measurement microphones, both outside the vehicle at the acoustic guide output and inside the vehicle to receive attenuated sound. By directing acoustic energy only to selected components of a vehicle via the acoustic guide, it is possible to test a specific component, such as a door or window without picking up extraneous noise which may be transmitted to the vehicle interior through other components or structure. This effect is achieved because no acoustic energy strikes the vehicle exterior except at the selected component. Also, since the test components remains attached to the vehicle, component dynamics with vehicle frame are not altered.

86-2157
Optimal Airframe Synthesis for Gust Loads
P. Hajela
Univ. of Florida, Gainesville, FL
Rept. No. NASA-CR-178047, 45 pp (Feb 1986) N86-20386/6/GAR

KEY WORDS: Aircraft, Wind-induced excitation, Random vibrations, Optimization

An optimization capability for sizing airframe structures that are subjected to a combination of deterministic and random flight loads is established. The random vibration environment intro-

duced the need for selecting a statistical process that best describes the random loads and permits computation of the dynamic response parameters of interest. It requires a formulation of design constraints that would minimize the conservativeness in the design and retain computational viability. The random loads are treated as a stationary, homogeneous process with a Gaussian probability distribution. The formulation of the analysis problem, the structure of the optimization programming system and a representative numerical example are discussed.

86-2158
GP-180 Wind Tunnel Flutter Test
A. Mazzoni, M. Pizzamiglio, R. Piaggio
Finale Ligure, Italy
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 581-588, 8 figs, 2 tables

KEY WORDS: Aircraft, Wind tunnel testing, Flutter

Properties of an elastic axis finite element model were used to develop a 0.175 scale wind tunnel model for flutter testing. Checks of the aeroelastic behavior were performed. The ground vibration test and wind tunnel entry were used to correlate the finite element model accuracy.

86-2159
Antenna Suitability for Aircraft Installation
D.E. McCoy
U.S. Army Technical Support Activity, Fort Monmouth, NJ
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 245-250, 6 figs, 2 tables, 2 refs

KEY WORDS: Case histories, Antennas, Helicopter equipment, Frequency response

A new radio system was recently developed for a variety of uses, one of which includes use in helicopters. A prototpye antenna was made by a contractor and submitted for testing in order to obtain flight safety approval. To determine the resonant frequencies of the antenna, an impulse frequency response test was conducted. This test indicated several resonant frequencies that matched helicopter forcing frequencies. Using the data taken during the impulse frequency response test the antenna was modeled on a modal analysis system showing the different modes of vibration. After reviewing the mode shapes several minor modifications were made to the antenna, with a frequency response test conducted after each modification. The impulse frequency response test indicated potentially hazardous vibration problems with this antenna.

MISSILES AND SPACECRAFT

86-2160
Modal Analysis Technique Used in Germany for Aerospace Structures
N. Niedbal
DFVLR Inst. of Aeroelasticity, Gottingen, W. Germany
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 378-385, 7 figs, 3 tables, 17 refs

KEY WORDS: Spacecraft, Experimental modal analysis

Modal-survey testing is an increasingly common part of the qualification procedure for aerospace structures, since it offers an experimental verification of normal mode parameters determined by dynamic finite element analysis. Moreover, it permits identification of structural damping, knowledge of which is essential for reliable flight-load calculations for space structures. A state of the art of modern modal-survey testing is given here, covering the phase-resonance method and various phase separation methods. The use of modal-survey results in the dynamic qualification of aerospace structures is discussed, emphasizing the correlation of analytical and experimental modal data. This aspect has attracted growing interest in recent years, due to the obvious need for convenient tools that allow finite element models to be updated with measured modal data.

86-2161
Comparison of Multiple Input Random and Sine Excitation Methods for Aerospace Structures
D.L. Hunt, B. Wendler, S. Soule
SDRC, Inc., San Diego, CA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 563-571, 5 figs, 5 tables, 4 refs

KEY WORDS: Spacecraft, Experimental modal analysis, Multipoint excitation technique, Periodic excitation, Random excitation

A modal test is usually required to verify an analytic model used in loads analysis for qualifying aerospace structures. This test defines important structural mode frequencies, mode

shapes, and damping and can be performed using any of a number of single and multiple input sine and random excitation methods. Very often, an orthogonality requirement is placed upon the measure modes which implies that very pure modes must be obtained. This need is further complicated when the measured modes, instead of the analytic modes, are used in the loads analysis. An overview of modal test methods and their application to a modal test of a communications satellite provides a comparison of the relative strengths and weaknesses of sine dwell and random excitation techniques.

86-2162
Modal Space Design for Active Vibration Control of Large Flexible Structures
H.V. Panossian
HR Textron, Inc., Valencia, CA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 167-170, 14 refs

KEY WORDS: Experimental modal analysis, Active vibration control, Spacecraft, Stochastic processes

Modal space design and control for stochastic linear systems is considered. Uncertainties in the frequencies, damping ratios, and mode shapes are assumed and the system dynamics is formulated in a stochastic model. The theory of eigensystem assignment is then treated for the above mentioned model under complete controllability and observability assumptions. Moreover, direct output feedback control is achieved under minimum mean square error between the desired and actual eigensystems.

86-2163
A Global Technique for Estimation of Modal Parameters from Measured Data
R.N. Coppolino, R.C. Stroud
The MacNeal-Schwendler Corp., Los Angeles, CA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 674-681, 6 figs, 3 tables, 8 refs

KEY WORDS: Modal analysis, Frequency response function, Global identification technique, Spacecraft

An automated method for estimation of structural vibration modes from measured frequency response data is described. The technique simultaneously treats an ensemble of measured responses and identifies a set of linearly independent displacement patterns exhibited by the data. In addition, generalized frequency response functions associated with the independent displacement patterns are identified. An effective dynamic system, described by the generalized frequency responses, is deduced from least squared considerations from which modal parameters of the structure are estimated.

86-2164
Evaluation of Techniques for Determination of Loads Due to Fluid-Structure Interaction
C. Stavrindis
ERNO Raumf.. rttechnik G.m.b.H., Bremen, Fed. Rep. Germany
Rept. No. ESA-CR(P)-2151, 227 pp (June 1985) N86-20491/4/GAR

KEY WORDS: Spacecraft, Finite element technique, Fluid-structure interaction, Computer programs

Finite element and classical methods for determining fluid-structure interactions in spacecraft are reviewed. For evaluation of fluid sloshing eigenfrequencies and fluid-structure coupled eigenfrequencies, three finite element computer programs were used. The ANSYS program includes nearly all features which are necessary for fluid-structure interaction calculations and only a few restrictions have to be considered, whereas NASTRAN (virtual mass method, fluid ring element method) is designed for special cases.

86-2165
Vibrations and Structureborne Noise in Space Station
R. Vaicaitis
Columbia Univ., New York, NY
Rept. No. NASA-CR-176520, 119 pp (Dec 31, 1985) N86-20485/6/GAR

KEY WORDS: Space stations, Structureborne noise, Spacecraft components, Fiber composites, Aluminum

Theoretical models were developed capable of predicting structural response and noise transmission to random point mechanical loads. Fiber reinforced composite and aluminum materials were considered. Cylindrical shells and circular plates were taken as typical representatives of structural components for space station habitability modules. Analytical formulations include double wall and single wall constructions. Pressurized and unpressurized models were considered. Parametric studies were conducted to determine the effect on structural response and

noise transmission due to fiber orientation, point load location, damping in the core and the main load carrying structure, pressurization, interior acoustic absorption, etc. These analytical models could serve as preliminary tools for assessing noise related problems for space station applications.

86-2166
Comparison of Predicted and Measured Acoustic Response of Components Mounted on Sandwich Panels
C.C. Trundle, Fei Hon Chu, G.F. Chilson, Jr.
RCA Astro-Electronics, Princeton, NJ
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 511-514, 4 figs, 4 refs

KEY WORDS: Spacecraft components, Panels, Sandwich structures, Modal analysis, Acoustic response

The need for test data to verify and improve analysis is still a necessary component of structure design. This is particularly true when acoustic loading is involved. However, it is vital to be able to predict, with reasonable accuracy, the responses of vibration-sensitive components in advance of testing. For the study presented, the acoustic response of differently sized sandwich panels with different components mounted on them provide a base of acoustic test data. Utilizing empirical relations which draw upon this database, the responses of the panels with components mounted on them are predicted. Actual test data for these panels are then compared to the predicted responses.

86-2167
Identification, Applications, and Dynamic Analysis of Nonlinear Spacecraft Components
I. Kolsch, H. Baier
Dornier System GmbH, Friedrichshafen, Fed. Rep. Germany
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 720-729, 15 figs, 10 refs

KEY WORDS: Spacecraft components, Experimental modal analysis

Spacecraft structures are generally linear, but some structural components and mechanisms reveal nonlinear characteristics. For systems that can be reasonably reduced to only a few degrees-of-freedom (local nonlinearities), methods which can be applied with reasonable effort are explained to identify the force/displacement and damping characteristic by static and sine sweep tests. The analytical treatment is based on Fourier expansions that include quasi-static accelerations and higher harmonics to cover shifts in the point of operation and subharmonic resonances. Conclusions are drawn for the design of nonlinear components and applied to actual spacecraft hardware. Problem areas such as the determination of the damping and spring coefficients, are treated. Reservations and limitations of traditional test philosophies and methods are shown.

MECHANICAL COMPONENTS

ABSORBERS AND ISOLATORS

86-2168
Frequency Dependence of Frame Dynamic Characteristics of Mineral and Glass Wool Materials
T. Pritz
Central Research and Design Institute for the Silicate Industry, Budapest, Hungary
J. Sound Vib., 106 (1) pp 161-169 (Apr 8, 1986) 8 figs, 2 tables, 17 refs

KEY WORDS: Vibration isolators, Acoustic insulation, Frames

The frequency dependences of the frame dynamic modulus of elasticity and loss factor of bonded mineral and glass wool materials measured in the range of 100 to 3000 Hz are reported. It is shown that both the dynamic modulus and the loss factor of the materials without air in the pores are independent of frequency in the range of measurement. The value of the loss factor is about 0·001 to 0·01, which is significantly smaller than those reported earlier.

86-2169
Reducing Turbo-Generator Noise and Vibrations with Dynamic Absorbers
J. Morel, P. Thomas, R. Vincent, I. Vuong
Electricite de France, Paris, France
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 526-531, 12 figs

KEY WORDS: Modal analysis, Dynamic vibration absorption (equipment), Turbogenerators, Noise reduction, Vibration control

The presence of a pronounced hum, at a frequency of 100 Hz, in the turbine hall is attributed to the turbogenerator sets. This constitutes a high rate of noise pollution and vibrations at 100 Hz may be the cause of material damage. As conventional soundproofing methods have proven to be inadequate in the reduction of emitted sound at 100 Hz, studies have been orientated towards the development of dynamic absorbers as a means of reducing vibration of the machines and therefore their emitted noise level. Use of such absorbers requires knowledge of the vibrational behavior of turbogenerators as well as of the occurrence of resonance at 100 Hz. Analyses are presented to assess the suitability of dynamic absorbers.

86-2170
An Application for Vibration Isolation of Rotating Machinery Using Computer Aided Design Programs (VID)
A. Nasser, A. El Khatib, S. Serag, H. Gaffer
Menoufia Univ., Shebin El-Kom, Egypt
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 329-333, 8 figs, 5 refs

KEY WORDS: Vibration isolation, Rotating machinery, Soil-foundation interaction, Computer aided design

A comparison is presented of experimental verses theoretical results obtained during the vibration isolation of rotating machinery. The soil parameters are taken into consideration and the mathematical model is solved using computer aided design programs (VID).

86-2171
Impact Limiter Retention Using a Tape Joint
A. Gonzales, R.G. Eakes
Sandia Natl. Labs., Albuquerque, NM
Rept. No. SAND-85-2283C, 2 pp (1986) DE-86001364/GAR

KEY WORDS: Impact limiters, Polyurethane resins, Foams

The beneficial uses shipping systems (BUSS) cask employs polyurethane foam impact limiters that fit onto the ends of the cask. A foam impact limiter takes energy out of a system during a hypothetical accident condition by allowing foam crush and large deformations to occur. This, in turn, precludes high stresses or deformations from occurring to the cask. Because of the need to transmit significant amounts of heat to the environment, the BUSS cask impact limiters were designed to shield a minimum amount of the cask surface area. With this design impact limiter retention after the initial impact resulting from the 9 meter regulatory drops becomes a concern. Retention is essential to ensure the cask does not experience higher stresses during any secondary or rebound effects without impact limiters than it does during the 9 meter regulatory drop with impact limiters in place.

86-2172
Vibrational Behavior of a Night Vision Scope Machine Gun Mounting Bracket Assembly
J.E. Ryan, K.J. LaSala
US Army Communications-Electronics Command, Ft. Monmouth, NJ
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 251-256, 8 figs, 4 refs

KEY WORDS: Case histories, Gun mounts, Experimental modal analysis, Structural modification techniques

Natural frequencies and mode shapes of a semi-cantilevered mount, used to interface a night vision scope to a 0.50 caliber machine gun, are studies to determine the overall night vision scope mounting bracket assembly dynamic behavior. With this information and information from further modal testing of other redesigned brackets, the engineer can determine whether a proposed design modification will produce the desired change in the dynamic behavior of the night vision scope mounting bracket. The practical importance of obtaining this information lies in the fact that redesigned brackets can be modal tested to determine which bracket is the best for live fire field testing. The time and money saved by using the computer-generated modal model for analyzing the redesign is significant.

86-2173
Vibration Response of Commercial Electronic Equipment in Military Environments
J.A. Habermeyer
SDRC, Inc., San Diego, CA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 760-766, 10 figs, 5 refs

KEY WORDS: Modal analysis, Electronic test equipment, Field test data, Shock isolation, Vibration isolation

Cost considerations make it advantageous to use commercial data processing equipment in military

appl ations such as mobile survivable systems. In order for this concept to be feasible, the commercial equipment must be able to withstand harsh shock and vibration environments. To determine the severity of these environments, an analysis of the vibration response of commercial electronic components mounted in a commercial cabinet rack, hard-mounted to a standard shelter, and subjected to rough terrain mobility and air transport loads was performed. Using various modeling tools and techniques, finite element and dynamic system models of the shelter and cabinet were developed and forcing functions determined. Modifications to the flexible cabinets to reduce loads on the electronic components were investigated.

86-2174
Dynamics of High Mobility Track Vehicles
M.K. McCullough, E.J. Haug
Univ. of Iowa, Iowa City, IA
J. Mech., Transm., Autom. in Des., Trans ASME, 108 (2), pp 189-196 (June 1986) 19 figs, 1 table, 13 refs

KEY WORDS: Suspension systems (vehicles), Tracked vehicles

A mechanical system superelement that represents spatial dynamics of high mobility track vehicle suspension systems is derived. Using results from a companion paper, the equations of motion for a suspension system with an arbitrary number of road wheels are systematically derived. Track is represented as a complex internal force element that acts between ground, wheels, and the chassis of the vehicle. Track tension is computed from a relaxed catenary relationship and track bridging effects are modeled. Numerical results for driver acceleration and absorbed power, as well as track tension are presented. A factor of 90 decrease in computer time is achieved over a comparable multibody model of the same vehicle.

86-2175
Optimum Nonlinear Suspension Systems
S.M. Metwalli
Univ. of Central Florida, Orlando, FL
J. Mech., Transm., Autom. in Des., Trans AMSE, 108 (2), pp 106-110 (June 1986) 5 figs, 11 refs

KEY WORDS: Isolators, Suspension systems (vehicles), Optimization

Global optimal isolation is presented. Results indicate that to optimally isolate a system, it should be totally disconnected from the disturbance. A model is then selected to optimize nonlinear suspension systems which, in the limits, approach optimal isolation characteristics. Nondimensional design parameters that themselves are made to be dependent on the input are employed. A step disturbance is selected to equivalently represent real excitations. The objective function incorporates the tire-terrain normal force as an indicator of the vehicle controlability which is unconstrained or constrained by a comfort criterion (acceleration). The advantages of optimized realistically nonlinear systems over their linear counterparts are indicated.

86-2176
Stochastic Optimal Control of Vehicles with Elastic Body and Active Suspension
A. Hac
Warsaw Technical Univ., Warsaw, Poland
J. Dynam. Syst., Meas. Control, Trans. ASME, 108 (2), pp 106-110 (June 1986) 5 figs, 11 refs

KEY WORDS: Suspension systems (vehicles), Active vibration control

A discrete-continuous vibration system, which can be treated as a model of a vehicle with an active suspension moving on a randomly profiled road, is considered. By the use of stochastic optimal control and estimation theory the suspension control forces and the steady-state behavior of an optimally controlled system in the presence of measurement errors are calculated and compared with the performance of an optimal passive system. The emphasis is on modeling and measurement problems. The need for taking body elasticity into account in the vehicle model is considered and the influence of sensor arrangement and accuracy upon the performance of the active system is determined.

SPRINGS

86-2177
Free Vibration of Coil Springs of Arbitrary Shape
K. Nagaya, S. Takeda, Y. Nakata
Gunma Univ., Gunma, Japan
Intl. J. Numer. Methods Engrg., 23 (6), pp 1081-1099 (June 1986) 12 figs, 16 refs

KEY WORDS: Springs, Curved beams, Transfer matrix method

A method for solving the vibration problem of coil springs of arbitrary shape is presented. In

the analysis the exact field transfer matrix is derived from the solution of the fundamental equation of the three-dimensional curved beam theory. The transfer matrix is given by combining this field transfer matrix and the point transfer matrix. The analysis derives the frequency equation which is applicable to coil springs of general shape. Numerical calculations are carried out for hyperboloidal springs and barrel springs.

86-2178
Mobility Analysis of Helical Coil Springs
Y.S. Unlusoy
Middle East Tech. Univ., Ankara, Turkey
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 446-452, 7 figs, 1 table, 18 refs

KEY WORDS: Modal analysis, Helical springs, Mobility functions

Dynamic behavior of helical compression springs as represented by their point mobility functions is investigated. Mass and stiffness matrices for the springs are obtained using straight beam finite elements with six degrees-of-freedom at each end. The effects of static axial load (i.e., preload) on the dynamic behavior are also taken into account. The eigenvalue problem is solved by the subspace iteration method and the undamped natural frequencies together with the corresponding modal vectors are determined. Theoretical point mobility functions are then calculated by the mode superposition method for excitation in the direction of longitudinal spring axis at one end of the spring while the other end is fixed. The calculated and experimentally obtained point mobility functions for three automobile suspension springs, drawn in the frequency range from 5 to 200 Hz, display very good agreement. The shapes of the first ten modes are also plotted and the major categories of vibration modes are identified. The effects of preload on the natural frequencies corresponding to each category of modes are identified. The results allow an assessment of the applicability of the widely used distributed parameter spring model which considers longitudinal spring vibrations only.

TIRES AND WHEELS

86-2179
Free Vibrations of a Tire as a Toroidal Membrane
S. Saigal, T.Y. Yang, H.W. Kim, W. Soedel
Purdue Univ., West Lafayette, IN
J. Sound Vib., 107 (1), pp 71-82 (May 22, 1986) 8 figs, 1 table, 18 refs

KEY WORDS: Tires, Mathematical models, Membranes, Vibration response, Inflatable structures

A tire is modeled as a toroidal membrane under internal pressure and mounted on a rim, to investigate its free vibration characteristics using a 12 degree-of-freedom rectangular membrane finite element. Such a modeling is valid if the tire is assumed to be incapable of supporting any weight in the absence of internal pressure. To verify the formulations of the membrane finite element, a flat rectangular membrane subject to in-plane loads and a circular cylindrical membrane under internal pressure are first analyzed. Analytical solutions for these cases are also derived. The analytical and numerical results are in good agreement. A toroidal membrane under internal pressure, assumed to model a low pressure tire, is also studied. Both the analytical derivation and the finite element solutions are presented. For the analytical solution the equations of motion yield a complicated differential equation for which an approximate solution is obtained by assuming that the parallel circle radius is constant as in the case of a bicycle wheel.

86-2180
On the Dynamic Response at the Wheel Axle of a Pneumatic Tire
L.E. Kung, W. Soedel, T.Y. Yang
J. Sound Vib., 107 (2), pp 195-213 (June 8, 1986) 16 figs, 3 tables, 13 refs

KEY WORDS: Pneumatic tires, Tire-wheel interaction, Suspension systems (vehicles)

A method for calculating the steady state displacement response and force transmission at the wheel axle of a pneumatic tire-suspension system due to a steady state force or displacement excitation at the tire to ground contact point is developed. The method requires the frequency responses (or receptances) of both tire-wheel and suspension units. The frequency response of the tire-wheel unit is obtained by using the modal expansion method. The natural frequencies and mode shapes of the tire-wheel unit are obtained by using a geometrically nonlinear, ring type, thin shell finite element of laminate composite. The frequency response of the suspension unit is obtained analytically. These frequency responses are used to calculate the force-input and the displacement-input responses at the wheel axle.

This method allows the freedom of designing a vehicle and its tires independently and still achieving optimum dynamic performance.

86-2181
Free Vibration of a Pneumatic Tire-Wheel Unit Using a Ring on an Elastic Foundation and a Finite Element Model
L.E. Kung, W. Soedel, T.Y. Yang
J. Sound Vib., 107 (2), pp 181-194 (June 8, 1986) 10 figs, 2 tables, 11 refs

KEY WORDS: Tire-wheel interaction, Pneumatic tires, Rings, Elastic foundations, Finite element technique

Natural frequencies and mode shapes of a pneumatic tire without suspension are investigated using a 12 degree-of-freedom, geometrically nonlinear, doubly curved, thin shell finite element of revolution with laminate composite materials. The wheel is assumed to be free to move within its own plane. To evaluate the finite element modeling, a simplified elastic ring-spring model is studied. The tire is modeled as a circular, elastic ring supported by distributed spring in both radial and circumferential directions. The wheel is modeled as a rigid mass to which the distributed spring is attached. The two models are found to agree and complement each other.

BLADES

86-2182
Dynamic Analysis of Thick Rotating Blades with Flexible Roots
B.A.H. Abbas
Univ. of Basrah, Basrah, Iraq
Aeronaut. J., 90 (1), pp 10-16 (Jan 1985) 7 figs, 4 tables, 13 refs

KEY WORDS: Blades, Finite element technique

This paper presents a new finite element model for the dynamic analysis of thick rotating blades with flexible roots. The new model is based on the fast convergent element developed by Abbas and Thomas which can satisfy all the geometric and natural boundary conditions of a thick nonrotating blade. It is the only element developed so far which can distinguish between roots of blades that are rigidly clamped and are elastically supported.

86-2183
A Development of Eigenvalue Perturbation Method for Linear Discrete Systems
Qiu Xiangjun, Zhu Shijing
Nanjing Aeronautical Institute, China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 556-562, 7 figs, 6 refs

KEY WORDS: Bladed disks, Perturbation method, Modal analysis

The relationship between vibration modes and physical and/or geometrical parameters of linear discrete models of structures is examined. The traditional method of dealing with this kind of problem is the eigenvalue perturbation method, which is valid only when the variations of structure parameters are limited within small ranges. To overcome this shortcoming the method of differential equations is developed from the eigenvalue perturbation method, and a set of differential equations is derived. It is shown that with the differential equation method the changes of vibration modes corresponding to the large-range variations of the structure parameters can be studied. Several conclusions about the characteristics of vibration modes are drawn and results of numerical computations and experiments on a bladed disk model are given.

BEARINGS

86-2184
Modal Analysis of Cylindrical Bearings
R.N. Dubey, B.G. Chalhoub
Univ. of Waterloo, Waterloo, Ontario, Canada
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 617-623, 4 figs, 10 refs

KEY WORDS: Cylindrical bearings, Modal analysis

Three dimensional equations of motion of isotropic elastic cylinders are solved for appropriate boundary conditions. The modal characteristics, natural frequencies and associated mode shapes are then used to obtain modal response of the system to different loading conditions.

86-2185
Whirl Instabilities in Pressure Step Bearings
J. Brindley, L. Elliott, J.T. McKay
Univ. of Leeds, Leeds, England
J. Appl. Mech., Trans. ASME, 53 (2), pp 430-435 (June 1986) 9 figs, 13 refs

KEY WORDS: Bearings, Whirling

The effect on the stability of a dynamically loaded journal bearing of introducing a pressure

step is examined by calculating numerically the whirl orbits described by the journal for a range of values of physical effects. In all full film cases the configuration is unstable in that the orbits spiral outwards to the bearing case; the tightness of the spiral is, however, much influenced by parameter values. The presence of appropriate cavitation permits a degree of stability, with the existence of stable whirl orbits. Cavity position and extent are vitally important to the stability characteristics, a result one would expect to be true of more realistic cavitation models than the single one used here.

86-2186
Modelling of the Normal Frictional Vibrations of Bearings
G. Massouros, A. Dimarogonas
Univ. of Patras, Patras, Greece
J. Sound Vib., 106 (1), pp 170-118 (Apr 8, 1986) 10 figs, 16 refs

KEY WORDS: Lubrication, Friction bearings

Normal vibrations are developed during sliding of a bearing working under mixed lubrication conditions. These vibrations are governed by the system inertia and the local flexibility of the interface layers. A simple model is used to support and verify experimental observations. Based on this model, analytical and experimental results are presented for the influence of the major governing parameters, such as the applied load on the vibration characteristics, i.e., frequency and amplitude of vibration. Secondary effects, such as velocity of sliding, are also discussed.

GEARS

86-2187
Cluttering Vibrations in Gearboxes of Motor Vehicles (Über Rasselschwingungen in Kix-Schaltgetrieben)
F. Kücükay, F. Pfeiffer
Technische Universität München, München, Fed. Rep. Germany
Ingenieur-Archiv, 56 (1), pp 25-37 (1986) 10 figs, 18 refs (in German)

KEY WORDS: Gear boxes, Motor vehicles, Chatter

In gearboxes of motor vehicles all components not being shifted to transmit torque may be excited to perform clattering vibrations. This type of oscillation can be resolved in a more or less stochastic sequence of impact taking place at the edges of the gear or bearing tolerances. The energy for this impulsive process comes from motor-engine vibrations in connection with a nonlinear behavior of the clutch. Based on an impulsive theory for multibody systems a method is presented to analyze these clattering vibrations. For optimizing the essential parameters of the system, i.e. excitation form, tolerances, damping, friction, a simulation program is developed. Clattering noise is assumed to be proportional to the energy losses due to impact at the edges of the plays. Results compare well with practical experiences.

86-2188
Stress Analysis of a Gear Tooth
M.L. Gambhir, A.K. Jindal
Thapar Institute of Engrg. & Tech., Patiala, India
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 767-772, 5 figs, 10 refs

KEY WORDS: Gear teeth, Finite element technique, Stress analysis, Mode shapes

The finite element technique is applied to study the stress distribution in a spur gear tooth. The stress analysis is carried out by assuming it to be a plane stress problem. The geometry of the gear tooth is modeled by variable node quadrilateral elements with nodes ranging from 5 to 9 having two degrees-of-freedom at each node. The bending and the contact stresses are obtained and their relative magnitudes are compared. The principal stress distribution has been plotted and the areas of stress concentration and those subjected to alternating stresses are identified. The contact stresses are found to be extremely large as compared to the bending stresses near the fillet regions. High tensile stresses have been found to occur a little below the critical contact point. The element has proved to be very efficient in modeling the curved geometry of a gear tooth.

86-2189
Maximum Entropy Spectral Line Estimation for Short Record Data of Gear and Gear-Train Errors
Yuanhong Lan, Zhaotong Wu
Chongqing Univ., Chongqing, China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 819-825, 9 figs, 4 tables, 14 refs

KEY WORDS: Gears, Spectrum analysis

Various methods for estimating frequencies, amplitudes and phases on the basis of maximum entropy spectrum are compared. Marple maximum entropy spectral line estimation (MMESLE) is proposed which includes parameter estimation for maximum entropy spectrum by Marple's fast recursive method, calculation of power spectrum and determination of frequencies by FFT, and estimation for amplitudes and phases by cyclic descent. In comparison with the conventional FFT spectral analysis, it has a higher estimation accuracy and resolution, especially suitable for the spectral analysis of short record data. The MMESLE is applied to the spectral analysis of spiral undulation errors of a helical gear and the differential train errors of a hobbing machine. It is shown that the main error sources can be exactly diagnosed. The results are satisfactory.

FASTENERS

86-2190
Identification of Dynamic Characteristics of Joints
C.-S. Zhao, M. Touratier, G. Coffinal
Nanjing Aeronautical Institute, China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 316-328, 9 figs, 4 tables, 13 refs

KEY WORDS: Linking analysis and test, Joints, Modal analysis, Parameter identification technique, Least-squares method

Some new developments in the research of the dynamic characteristics of joints between substructures are described. In order to establish a mathematical model of the structures, a new method that can determine the dynamic parameters of joints between substructures is presented. The dynamic parameters of structures can be obtained by measured frequency response data of the whole structure through a least-squares fit.

86-2191
Damping in Bolted Beam-Column Connections Under Pulsating Loads
A.K. Aggarwal, R.C. Coates
Univ. of Technology, Papua, New Guinea
The Structural Engineer, 63B (2), pp 27-33 (June 1985) 12 figs, 1 table, 12 refs

KEY WORDS: Bolted joints, Beam-columns, Energy absorption, Damping coefficients, Pulse excitation

Moment resistant steel beam-column connections using endplates and high strength friction grip bolts have been tested under both static and pulsating loads to determine their energy absorption characteristics. The effect of endplate thickness on damping capacity has been considered for a constant bolt diameter and member cross-section. Six specimens, two each made using 20 mm, 16 mm, and 12 mm thick endplates were tested -- three under static loads and the other three under pulsating loads. An optical technique was used for the measurement of rotations of the beam and column. Loss of bolt tension under pulsating loads was also considered. The use of a flexible endplate capable of transferring the full plastic moment of the beam is recommended for these connections.

SEALS

86-2192
Experimental Determination of Dynamic Coefficients of Turbulent Seal Clearances in Turbopumps (Experimentelle Ermittlung dynamischer Koeffizienten für turbulente Dichtspalte in Turbopumpen)
H. Massmann, R. Nordmann
Fahrzeugschwingungen, Bauwerksschwingungen, Rotordynamic-Systemanalyse und-Identifikation-, VDI Ber. 536, pp 171-190 (1984) 9 figs, 1 table, 10 refs (in German)

KEY WORDS: Seals, Clearance effects, Inertial forces, Damping coefficients, Stiffness coefficients

Dynamic fluid flow loads on ring clearances, used as seals in turbopumps, can be described by inertia, damping, and stiffness parameters. Those values can be measured, as well as determined theoretically. From the recorded impulse response signals of a test model simulating seal clearance, the complex elasticity function is calculated by means of FFT. By the variation of seal clearance in an analogous mechanical model the theoretical transfer functions are adjusted to measurement and the optimum coefficients are determined. Measurement results for various seal clearance conditions (speed, axial velocity) are presented and compared with theoretical clearance models.

STRUCTURAL COMPONENTS

STRINGS AND ROPES

86-2193
A New Dynamic FEM of Frames Developed from Timoshenko Beam Model
Yin Xuegang, Chen Huai

Chongqing Univ., Chongqing, China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 283-289, 3 figs, 3 tables, 5 refs

KEY WORDS: Modal analysis, Frames, Timoshenko theory

Based on the Timoshenko beam model, a new dynamic finite element model (FEM) of frames, considering the effects of shearing deformation and rotatory inertia of the beam, is developed. Dynamic constraint mode functions in a element are derived from the governing equations of Timoshenko beam recurrently. Then the corresponding stiffness and mass matrices of elements are derived from the element shape function matrices. The assembling of the element matrices to the global ones is similar to current FEM. The eigenproblem obtained finally for free vibration of a structure is a linear one. The new dynamic FEM can be applied to find the higher eigenpair. Compared with J.S. Przemieniecki's dynamic FEM in the same accuracy, the new method is simpler and the size of the element can be much bigger. Therefore the degree-of-freedom of the discretized model can be greatly reduced. Numerical examples show that this method is effective and convenient for solving the higher eigenproblem of free vibration of a structure. The CPU time and the storage of the calculation will be reduced greatly.

86-2194

Transient Response of a String on an Elastic Base

D.P. Thambiratnam
National Univ. of Singapore, Kent Ridge, Singapore

J. Sound Vib., 105 (2), pp 275-282 (Mar 8, 1986) 7 figs, 1 table, 10 refs

KEY WORDS: Strings, Elastic foundations, Transient response

The transient response of a stretched string resting on an elastic base and subjected to impulsive end loading is examined. The analysis is based on the concept of a wave as a carrier of discontinuities in the field variable and its derivatives. These discontinuities are determined from a recurrence relation which is in turn generated by using a time-harmonic asymptotic series solution to the equation of motion. Numerical examples are treated where the responses of the string to delta and step function boundary loads are obtained. The results confirm the influence of the base modulus on the transient displacement, velocity and slop distributions in the string. The distortion of the transients and the discontinuities in the velocity and slope are evident from the results presented. The transient response of the string due to other boundary conditions can be obtained by using the present results.

CABLES

86-2195

A Probabilistic Approach to Achieve Protection Against Different Modes of Transmission Line Vibration

R.K. Chan, P.R. Ukrainetz, M.W. Wilson
Saskatchewan Power Corp., Regina, Sask., Canada

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 634-640, 1 fig, 1 table, 8 refs

KEY WORDS: Transmission lines, Wind-induced excitation, Fatigue life

This paper presents a probability-based technique to determine the optimal location of damper placement for conductor vibration protection. The primary objective of this approach is to include the following important parameters in the analysis of the damper placement: the overhead transmission line design parameters, the field data which indicates the occurrence or the probability of conductor vibration at different amplitudes and frequencies, the amount of fatigue damage due to different vibration amplitudes and frequencies, the performance characteristics of the damper at different vibration amplitudes and frequencies, and the probability of placement error in the installation of the damper.

BARS AND RODS

86-2196

The Transient Field Under a Point Force Acting on an Infinite Strip

L.M. Brock
Univ. of Kentucky, Lexington, KY

J. Appl. Mech. Trans. ASME, 53 (2), pp 321-325 (June 1986) 4 figs, 11 refs

KEY WORDS: Bars, Impact response

As a prelude to studying the transient stresses in a notched bar under impact, the transient stress and velocity field in the cross-section under a point force acting on one surface of an infinite elastic strip is examined. The point force is

suddenly applied and normal to the surface. By transform methods, closed-form expressions for the transient field are obtained and used to study the multiple wave reflection process. In particular, the normal stress on the cross-section, tensile for the most part before the arrival of reflections, subsequently becomes essentially compressive.

86-2197
Approximation and Measurement of the Basic Branch of a Dispersion Curve of Longitudinal Rotationally Symmetrical Waves in Circular Cylindrical Bars
J. Hegr
Elektrotechnicka fakulta CVUT, Prague, Czechoslovakia
Acta Technica CSAV, 31 (2), pp 261-272 (1986) 9 figs, 1 table, 6 refs

KEY WORDS: Bars, Wave propagation

The dispersion curve of longitudinal rotationally symmetrical waves in circular bars of infinite length is defined by a complex transcendental equation. The paper presents a very accurate approximation of the basic dispersion curve, expressed by a simple function. The results of measuring the basic dispersion curve by an electroacoustic impulse method on a circular bar of finite length are shown. The particular points of the dispersion curve obtained experimentally coincide very well with the theoretical curve of the bar of infinite length. The possibility of the nondestructive measurement of the value of the Poisson ratio is suggested.

86-2198
One-Dimensional Finite Elements in Non-Stationary Elastodynamics
M. Okrouhlik, C. Hoschl
Ustav Termomechaniky CSAV, Prague, Czechoslovakia
Acta Technica CSAV, 30 (3), pp 283-303 (1985) 22 figs, 2 tables, 14 refs

KEY WORDS: Bars, Elastodynamic response, Finite element technique

A simple mechanical problem, the nonstationary propagation of stress waves in a thin bar, whose exact solution is known, is used as an etalon for testing the behavior of Lagrangian and Hermitian one-dimensional finite elements in nonstationary dynamics and various step-by-step methods of integration in time. Certain advantages of Hermitian against Lagrangian elements are shown and comparison of integration methods in terms of their errors, computer memory and time requirements are presented.

86-2199
Structural Integrity Testing of Utility Poles Based on Modal Distribution
D.E. Franklin, M.W. Murphy, R.A. Palylyk
British Columbia Hydro Research and Development, Surrey, BC, Canada
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 88-93, 4 figs, 7 refs

KEY WORDS: Correlation techniques, Modal analysis, Rods, Stiffness coefficients, Linking analysis and test

A nondestructive test procedure that reliably measures the residual stiffness of in-service wood utility poles has been developed. A correlation coefficient of 0.82 has been achieved between the measured static stiffness and the predicted dynamic stiffness based on modal distribution. Application of the technology is currently underway in Canada in parallel with conventional methods of testing the structures.

86-2200
Periodic and Non-Periodic Combination Resonance in a Non-Linear System of Rods
A. Forys
Technical Univ. of Krakow, Krakow, Poland
J. Sound Vib., 105 (3), pp 461-472 (Mar 22, 1986) 4 figs, 1 table, 7 refs

KEY WORDS: Rods, Parametric resonance

Periodic and nonperiodic combination resonances in a system of three rods with articulated joints are analyzed. The resonances have a parametric nature. The couplings of elements of the system through internal longitudinal forces, which are transverse forces at the ends of neighboring rods, are taken into account. The resonance curves for stationary states are investigated and comparisons with resonance curves for internal resonance are made. In the equations of motion nonlinear terms appear. They are connected with damping and have a geometrical nature. The mathematical analysis of the equations is accomplished by using Tondl's method. Plots of amplitudes against frequency are presented.

BEAMS

86-2201
Modal Analysis of a Cantilever with Changing Stiffness and with Added Concentrated Mass
P.Q. Zhang, T.-X. Song, T.C. Zhang

Univ. of Wisconsin, Madison, WI
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 787-794, 5 figs, 5 tables, 6 refs

KEY WORDS: Cantilever beams, Variable material properties, Modal analysis

Extensive analytical study has been made for a cantilever beam with changing stiffness at the support end and at various positions along the beam and for a cantilever beam with added concentrated mass. Results have been obtained for each case with both displacement and strain modes. It has been found that the same trend exists for the strain modes due to changing stiffness and the displacement modes due to added concentrated mass.

86-2202
Resonant Vibrations of a Submerged Beam
J.D. Achenbach, J. Qu
Northwestern Univ., Evanston, IL
Sound Vib., 105 (2), pp 185-198 (Mar 8, 1986) 4 figs, 1 table, 24 refs

KEY WORDS: Beams, Submerged structures, Resonant response, Integrodifferential equation, Matched asymptotic expansion technique

Forced vibration of a simply supported submerged beam of circular cross section is investigated by the use of two mathematical methods. In the first approach the problem formulation is reduced to a singular integro-differential equation for the transverse deflection. In the second approach the method of matched asymptotic expansions is employed. The integro-differential equation is solved numerically, to yield an exact solution for the frequency response. Subsequent use of a representation integral yields the radiated far field acoustic pressure. The exact results for the beam deflection are compared with approximate results that are available in the literature. A matched asymptotic expansion is worked out by constructing inner and outer expansions for frequencies near and not near resonance frequencies, respectively. The two expansions are matched in an appropriate manner to yield a uniformly valid solution. The leading term of the matched asymptotic solution is compared with exact numerical results.

86-2203
Theoretical Studies on Flexural Wave Propagation in Beams: A Comprehensive Review. Part III: Wave Propagation in Beams with Discontinuities of Cross Section
M.M. Al-Mousawi
Univ. of Aberdeen, Aberdeen, Scotland
Shock Vib. Dig., 18 (6), pp 11-18 (June 1986) 59 refs

KEY WORDS: Beams, Wave propagation, Flexural waves, Elastic waves, Discontinuity-containing media

A comprehensive review related to the problems of flexural wave propagation in beams is presented in three parts. Part I is a historical background. Part II describes the use of Timoshenko beam theory, including the effect of shear distortion and rotatory inertia, for vibrational and transient analysis of beams. Part III covers elastic stress wave propagation in beams with discontinuities of cross section.

86-2204
Harmonic Wave Propagation in Materials with Periodic Beam-Structure
K.S. Kim, R.L. Piziali
Washington Univ., St. Louis, MO
J. Sound Vib., 107 (1), pp 59-70 (May 22, 1986) 9 figs, 20 refs

KEY WORDS: Beams, Periodic structures, Harmonic waves, Wave propagation

The characteristics of harmonic waves propagating in periodic beam structures are investigated. A very effective method for the calculation of dispersion relations of elastic waves in these materials is developed by applying the dynamic theory of crystal lattices to discrete models of periodic beam structures. This method is applicable to general three-dimensional periodic beams structures. Results presented show that the solutions converge to the exact solution as the number of atoms in the discrete models increases. The dispersion relations of plane harmonic waves in the micropolar continuum model are also calculated. They are compared with the exact solutions to examine the applicability of the continuum models to dynamic problems.

86-2205
Field-Consistency and Violent Stress Oscillations in Finite Element Method
G. Prathap, C.R. Babu
Natl. Aeronautical Lab., Bangalore, India
Rept. No. NAL-TM-ST-8506, 43 pp (June 1985) N86-21234/7/GAR

KEY WORDS: Beams, Finite element technique

The fact that finite element models can give rise to violent stress oscillations has been known for

some time. However, it is less well known that these oscillations arise in a specific class of problems where there are multiple strain-fields arising from one or more field-variables and where one or more of these strain-fields must be constrained in particular physical limits. In this paper it is shown that unless the interpolations for these constrained strain-fields are field-consistent, violent oscillations would set in. The field-consistency interpretation offers a conceptual scheme to delineate these problems and an operational procedure, the functional reconstitution technique, allows the errors resulting from field-inconsistency to be anticipated a priori. The power of this approach is demonstrated through an interesting example of a multi-[illegible]in field, multi-field variable problem -- the [illegible]sional deformation of a shear flexible curve[illegible]beam.

86-2206
Steady State Response of an Axially Moving Strip Subjected to a Stationary Lateral Load
S. Chonan
Tohoku Univ., Sendai, Japan
J. Sound Vib., 107 (1), pp 155-165 (May 22, 1986) 6 figs, 1 table, 17 refs

KEY WORDS: Moving strips, Beams, Rotatory inertia effects, Transverse shear deformation effects, Periodic response

The steady state response of an axially moving strip subjected to a constant lateral force fixed in space is studied. The problem is studied on the basis of a thick beam theory which takes into account the effects of rotatory inertia, shear deformation and the second-order term in the normal stress due to the rotation of the strip. The steady state solution is determined analytically by applying the Laplace transform method with respect to the axial space variable. Critical speeds of the strip for which a resonance effect occurs in the system are obtained extensively for a wide range of parameters involved and compared with those from the classical thin beam theory. The displacement and moment profiles of the strip are obtained and shown graphically for several values of the axial tensile force and speed of the strip.

86-2207
Modified Torsional Vibration Analysis of Multi-Mass Shaft Systems
M. Ghosh, A. Rajamani
Bharat Heavy Electricals Limited, Hyderabad, India
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 101-106, 7 figs, 1 table, 3 refs

KEY WORDS: Linking analysis and test, Multi-beam systems, Torsional vibrations, Natural frequencies, Modal analysis

A method is developed to compute the torsional natural frequencies of a multi-mass shaft system with experimentation on a test rotor and application to a motor-compressor problem. In this method, the coefficients of the polynomial corresponding to frequency equation are determined by the method of Crossley-Gormen. The roots of the polynomial are used to result in zero end torque at the free end. The theoretical results are compared with the experimental results obtained on a test rotor by impact excitation. The method was also applied to a motor-compressor system which has the problem of motor cooling fan blade failures

86-2208
Dynamic Finite Element and Experimental Modal Analysis of a Trashrack for Use in a High Velocity Flow
R.R. Boentgen, A.G. Behring, B.G. Allen, C.-H. Yeh
Teledyne Energineering Services, Waltham, MA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 223-232, 14 figs, 3 tables

KEY WORDS: Grids (beam grids), Hydraulic turbines, Experimental modal analysis, Case histories, Finite element technique

A trashrack for a hydroelectric power project is to be subjected to an unusually high water velocity. For the design of the trashrack, a finite element analysis was performed to compute the stress distribution in the structure using an assumed damping value. Modal testing was performed on a prototype trashrack panel to confirm the mode shapes and natural frequencies predicted by the mathematical model, and to confirm that assumed damping values are conservative. A set of modal analysis experiments was performed to estimate the contribution to damping of several design features, including rubber pads, protective coating and foam fill. Testing was conducted on an uncoated and unmounted structure, on a coated but unmounted structure, on a coated structure mounted in a test facility, and on a coated and mounted structure under water. Damping was estimated by curve-fitting and modal responses. In general, the results of the modal analysis testing work compared favorably with results predicted by the finite element model and actual damping was found to be conservative.

FRAMES AND ARCHES

86-2209
Structural Dynamic Modifications Using Mass Additive Technique
H. Kanda, M.L. Wei, R.J. Allemang, D.L. Brown
Yanmar Diesel Engine, Kyoto, Japan
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 691-699, 8 figs, 7 tables, 5 refs

KEY WORDS: Frames, Modal analysis, Structural modification techniques, Mass additive technique, Frequency response functions

The application of a mass additive technique to the structural dynamics modification of an H-frame is presented. This technique employs a mass additive procedure where rigid masses are mounted to the structure at the points of interests. Frequency response functions and the enhanced modal parameters of all six degrees-of-freedom were estimated at the attachment points. The added masses were analytically removed in the modal modeling program. The validity of the inertially loaded modal model was also checked by comparing the mass modification results with the measured modal data of the original H-frame. The modal parameters of the original H-frame were enhanced by the shift of the system's damped natural frequencies due to the removal of the added masses. A modal tuning procedure was developed to rescale the extracted modal vectors to compensate the errors existing in the modal data base. Finite element analysis results were used to correlate with the modal test and hardware modification outcomes.

86-2210
The Effect of Longitudinal Motion and Other Parameters on the Bending Eigenfrequencies of a Simple Frame
A. Alexandropoulos, G. Michaltsos, A. Kounadis
National Technical Univ., Athens, Greece
J. Sound Vib., 106 (1), pp 153-159 (Apr 8, 1986)
2 figs, 3 tables, 9 refs

KEY WORDS: Frames, Flexural vibration, Rotatory inertia effects, Hamiltonian principle, Translational inertia effects

Using the variational Hamilton's principle, the equations of free motion of a simple two-bar frame carrying a concentrated mass with rotational inertia at its joint are established. The effect on the bending eigenfrequencies of the longitudinal motion, alone or in combination with other parameters, is thoroughly discussed. These parameters are the translational and rotational inertia of the joint mass, the length and slenderness ratios of the two bars, and the stiffness ratio. The variety of the numerical results presented herein provides a better insight into the actual flexural motion of frames when the effect of longitudinal motion is taken into account.

86-2211
The Dynamic Analysis and Experimental Research of a Radar Antenna Frame
Xu Qingyu, Luo Xiaoyu, Qiou Yang
Xi'an Jiaotong Univ., Shaanxi, China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 371-377, 7 figs, 1 table, 8 refs

KEY WORDS: Frames, Antennas, Modal analysis, Substructuring methods

In order to raise the tracing accuracy of a radar, dynamic analysis must be taken for design of the radar antenna frame. The connected loading dynamic substructural method is presented for calculating its dynamic character. By means of the accurate dynamic condensatic method and bicoordinate conditions, the dynamic effect of slave substructures is put to a main substructure. An improved algorithm of nonlinear given problems is used to calculate the lowest four eigenpairs of the antenna frame.

86-2212
Study on Load Effects of Vibrating Substance on the Surface of a Vibrating Screen Machine by Mechanical Impedance Method
Han Erh-Chung, Guo Xing-Huie
Northeast Univ. of Technology, Liao-Ning, China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 708-711, 3 figs, 6 refs

KEY WORDS: Frames, Screening, Vibratory techniques, Mechanical impedance, Experimental modal analysis

In the screening machine design, the dynamic behavior and stress responses of a screen frame must be studied. There are many structural analysis programs which may be used, but the acting loads on a screen frame are unknown. The load effects of a vibrating substance acting on a screen frame are studied. By the experimental mechanical impedance method, it is found that the load effects of the vibrating substance is a series of impulse forces and the formula for this dynamic load is established. The results may be used in the dynamic stress calculation of a screen machine frame.

MEMBRANES, FILMS, AND WEBS

86-2213
Free Vibration of an Elliptic Ring Membrane Clamped Along Two Confocal Ellipses
A.N. Verma, L.S. Kothari
Deshbandhu College, New Delhi, India
J. Sound Vib., 105 (2), pp 211-215 (Mar 8, 1986) 1 table, 8 refs

KEY WORDS: Membranes, Rings, Natural frequencies, Mode shapes

Free vibration of an elliptical ring membrane clamped along two confocal ellipses is studied analytically, and the natural frequencies are tabulated for the first four modes of vibration.

PLATES

86-2214
Effects of Edge Restraints on the Non-Linear Flexural Vibrations of an Imperfect Cross-Ply Laminated Plate Resting on an Elastic Foundation
A.P. Bhattacharya
Univ. of the West Indies, St. Augustine, Trinidad, West Indies
J. Sound Vib., 105 (2), pp 265-274 (Mar 8, 1986) 2 figs, 2 tables, 19 refs

KEY WORDS: Plates, Elastic foundations, Flexural vibrations

A solution is presented, for the nonlinear Marguerre dynamic equilibrium and compatability equations, for the large amplitude free flexural vibrations of an imperfect, cross-ply, laminated plate, having elastically restrained edges and resting on an elastic foundation. The analysis is used to study the effects of edge restraints and elastic foundation constants on the frequency ratios of isotropic and CFRP plates. Numerical results are presented graphically.

86-2215
Non-Linear Vibration and Postbuckling of Isotropic Thin Circular Plates on Elastic Foundations
P.C. Dumir
Indian Institute of Technology, New Delhi, India
J. Sound Vib., 107 (2), pp 2153-263 (June 8, 1986) 6 tables, 22 refs

KEY WORDS: Circular plates, Elastic foundations

An approximate solution for the large deflection axisymmetric responses of isotropic thin circular plates resting on Winkler, Pasternak and nonlinear Winkler foundations is presented. Plates with edges elastically restrained against rotation and in-plane displacement are considered. Von Kármán type equations in terms of transverse deflection and stress function are employed. A one term mode shape is used to approximate the transverse deflection and Galerkin's method is used to obtain an equation for the central deflection which has the form of a Duffing's equation. Nonlinear frequencies, postbuckling response to radial load at the edge and the maximum transient response to transverse step load have been obtained. It is shown that sufficiently accurate results are obtained by this method. Numerical results are presented to illustrate the effect of various parameters.

86-2216
Active Control of Elastic Plates
H.H.E. Leipholz, M. Abdel-Rohman
Univ. of Waterloo, Waterloo, Ontario, Canada
Ingenieur-Archiv, 56 (1), pp 55-70 (1986) 4 figs, 15 refs

KEY WORDS: Plates, Active control

Structural control frequently involves the control of continuous structural components leading to problems described by partial differential equations. Since in addition the control operator makes the problems in many cases non-selfadjoint, one is faced with a non-trivial situation. Due to nonselfadjointness, design based on a modal technique may exhibit spillover: That is instability of the controlled system due to the detrimental effect of higher modes which have been neglected in the design. Therefore, the design should be based on closed form solutions. In this paper it is shown that for a plate such closed form solutions can be found. It is also shown that the controlled plates behave satisfactorily, and it is indicated that the structural parameter associated with the non-selfadjoint control operator should be positive, yet limited from above, in order to ensure an adequate and stable response of the controlled plate.

86-2217
The Extent of the Stress Intensity Factor Field During Crack Growth Under Dynamic Loading Conditions
C.C. Ma, L.B. Freund
National Taiwan Univ., Taipei, Rep. of China
J. Appl. Mech., Trans. ASME, 53 (2), pp 303-310 (June 1986) 7 figs, 15 refs

KEY WORDS: Plates, Stress intensity factors, Crack propagation

The phenomenon considered is fracture initiation and crack growth in a plate due to dynamic pressure loading on the faces of a pre-existing crack. The problem is formulated within the framework of two-dimensional elastodynamics, and the system is viewed as a semi-infinite crack in an otherwise unbounded body. The ratio of the normal stress on the fracture plane to the value due to the singular term in the stress field alone is computed for some point at a small fixed distance ahead of the crack tip, with a view toward establishing the conditions under which the stress intensity factor controlled singular term accurately describes the near tip stress distribution in this highly transient process. Measured and calculated histories compare very well for relatively low crack face pressures, but there is significant disagreement beyond crack growth initiation for higher pressures. Possible reasons for the discrepancies are discussed.

86-2218

Comparisons of Finite Element Method and Experimental Modal Analysis of a T Plate with Various Boundary Conditions

I.C. Wang, M.L. Wei, J.-C. Wei
Univ. of Cincinnati, Cincinnati, OH
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 748-753, 6 figs, 6 tables, 4 refs

KEY WORDS: Plates, Finite element technique, Experimental modal analysis, Boundary condition effects

A full comparison and discussion of the natural frequencies and mode shapes of a steel T plate are presented by making use of the finite element method and experimental modal analysis techniques. Several finite element models of the T plate were constructed using various finite element computer codes such as NASTRAN, ANSYS, and GIFTS. Finite element analysis (FEA) results are compared with the modal parameters extracted from the experimental modal test data. Various boundary conditions were applied to the T plate's mathematical model in the FEA. During modal testing, the impact excitation technique was used to acquire the frequency response functions of the T plate. Correlation of the analytical and experimental results was performed to adjust the finite element models to match the experimental test data. From the numerical results, conclusions are made with respect to the accuracy of the estimated modal parameters of the T plate.

86-2219

A Review of Dynamic Behavior of Stiffened Plates

A. Mukherjee, M. Mukhopadhyay
Indian Institute of Technology, Kharagpur, West Bengal, India
Shock Vib. Dig., 18 (6), pp 3-8 (June 1986) 85 refs

KEY WORDS: Stiffened plates, Reviews

The paper is a review of analytical and numerical tools for studying dynamic behavior of stiffened plates. The various approaches include orthotropic plate approximation, grillage approximation, and plate and beam idealization.

86-2220

Free Vibration and Buckling Analysis of Clamped Skew Sandwich Plates by the Galerkin Method

S.S.F. Ng, B. Das
Univ. of Ottawa, Ottawa, Canada
J. Sound Vib., 107 (1), pp 97-106 (May 22, 1986) 1 fig, 6 tables, 12 refs

KEY WORDS: Skew plates, Sandwich structures, Vibration response, Galerkin method

Galerkin's variational method has been used in the past by several investigators to solve bending problems of clamped skew plates. In this paper the suitability of the Galerkin method for solution of problems of buckling under the action of in-plane forces and of free vibration of skew plates is studied. The method is first applied to investigate the problems for clamped rectangular sandwich plates. After the validity of the method has been established, the method is then extended to analyze similar problems for clamped skew sandwich plates. The governing differential equations for the skew sandwich plates are obtained by transforming the corresponding differential equations in Cartesian coordinates into skew coordinates. The parameters considered herein for the buckling and free vibration behavior of the skew sandwich plates are the aspect ration of the plate, Poisson's ratio, skew angle and various shearing stiffnesses of the core. Simplicity and quick convergence is the advantage of the method in comparison with other much more laborious numerical methods requiring extensive computer facilities.

86-2221

Axisymmetric Dynamic Behaviour of Thick Plate Subjected to Impulsive Loads

S.-I. Suzuki

Tsujido Hagashi-kaigan, Fujisawa, Japan
J. Sound Vib., 105 (2), pp 339-345 (Mar 8, 1986) 5 tables, 9 refs

KEY WORDS: Plates, Impulse response

Analysis is carried out for the case where a thick circular plate is subjected to impulsive loads. The fundamental equations governing the displacement are introduced, with use of equilibrium conditions. The relationships between frequencies and R/h (radius/thickness) are obtained and they are compared with those given by Mindlin theory. For the case where the fundamental equation is introduced by the variational calculus, it is necessary to notice whether restrained conditions are satisfied or not.

86-2222
Natural Frequencies of Rectangular Plates with Free Edges
T. Mizusawa
Daido Institute of Technology, Nagoya, Japan
J. Sound Vib., 105 (3), pp 451-459 (Mar 22, 1986) 4 tables, 13 refs

KEY WORDS: Rectangular plates, Natural frequencies, Rayleigh-Ritz method, Poisson's ratio

Vibration analysis of isotropic rectangular plates with free edges by the Rayleigh-Ritz method with B-spline functions is presented. To show the accuracy of the present method, the results are compared with existing results based on other numerical methods and found to be in good agreement. Accurate frequencies of rectangular plates are analyzed for different aspect ratios and boundary conditions. The effects of Poisson's ratio on natural frequencies of square plates with free edges are also investigated.

86-2223
Determination of Elastic Constants of Orthotropic Plates by a Modal Analysis/Rayleigh-Ritz Technique
L.R. Deobald, R.F. Gibson
Univ. of Idaho, Moscow, ID
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 682-690, 1 fig, 5 tables, 17 refs

KEY WORDS: Modal analysis, Plates, Rayleigh-Ritz method, Finite element technique, Computer programs

The first part of this paper describes a computer program which uses equations derived by the Rayleigh-Ritz technique to model the vibrations of rectangular orthotropic plates. The characteristic functions of vibrating beams were used as the assumed functions for plates with boundary conditions consisting of clamped and free edges. Resonant frequencies and mode shapes from the program were verified by finite element analysis and modal analysis for square aluminum and graphite/epoxy plates. The plate vibration model was then incorporated into a second computer program which was designed to use the measured resonant frequencies of orthotropic plates to determine the four apparent elastic constants. Resonant frequencies measured by an impulse technique were used to determine two Young's moduli, the in-plane shear modulus, and a Poisson's ratio for each plate.

86-2224
Analytical and Experimental Modal Analysis of Orthotropic Plate-Type Structures
D.A. Blessen., G.C. Pardoen
Newport Corp., Fountain Valley, CA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 754-759, 7 figs, 6 tables, 8 refs

KEY WORDS: Plates, Experimental modal analysis, Finite element technique

The vibration characteristics of orthotropic plate-type structures, using finite element and experimental modal analysis techniques, are presented. The plate bending model consists of a high-order, extremely efficient, triangular element in the development of both the mass and the stiffness matrices. This element, with five degrees-of-freedom per node, can easily be adapted to include shell bending analysis. The finite element solution technique has been used to analyze both the static and the dynamic responses of variously supported composite plates. The experimentally derived results are obtained using classical modal analysis techniques.

86-2225
Prediction of Loss Factors Due to Squeeze Film Damping Mechanisms
L.C. Chow, R.J. Pinnington
Southampton Univ., England
Rept. No. ISVR-TR-130, 92 pp (Oct 1985) PB86-177920/GAR

KEY WORDS: Plates, Squeeze-film dampers, Loss factors, Impedance technique

The damping on plates due to the squeeze film motion is predicted using an impedance approach

in which the response of infinite coupled layers may be predicted by assigning an impedance per unit area to each layer. Such a model is valid provided that the damping associated with the plate area is more than any edge contributions.

86-2226
Response and Damping of a Rectangular Cantilever Plate with Vibrating Beam Dampers
A. Arpaci, M. Savci
Technical Univ. of Istanbul, Istanbul, Turkey
J. Sound Vib., 107 (2), pp 243-252 (June 8, 1986) 9 figs, 16 refs

KEY WORDS: Rectangular plates, Damped structures, Ritz method

The use of beams as auxiliary mass dampers for cantilever plates is considered. Because the cantilever plate problem, which is of strong industrial interest, does not lend itself to a Levy-type solution, the procedure developed by Ritz is used. Structural damping is incorporated into the main and auxiliary systems by treating them as having a complex elastic modulus. With appropriate selection of the parameters, the fundamental resonance of the plate is split into two new ones with considerably suppressed responses. In order to verify the analysis, an experimental investigation was carried out and the results obtained were compared with the theory developed.

SHELLS

86-2227
Resonance Response of Thin Shells
A. Tesar
Ustav Stavebnictva a Architektury, Bratislava, CSSR
Acta Technica CSAV, 30 (1), pp 88-103 (1985) 9 figs, 18 refs

KEY WORDS: Shells, Resonant response, Finite element technique

Discrete numerical studies of the resonance response of thin shells in nonlinear regions of vibrations are presented. The general analysis of motion is carried out on the ground of the FETM method, employing the problem-oriented combination of the transfer matrix and the finite element techniques. The multigrid spatial discrete simulation is used for the geometric representation of the shell structure and anisotropy of the material. Generalized transfer hypermatrices of the FETM-method are constructed over the diagonal set-up of linear and nonlinear transfer matrices pertaining to particular micro-element of the discrete simulation under consideration. The transfer matrices are derived through inverse transformations of corresponding stiffness matrices. Theoretical analyses are applied to an illustrative numerical solution of nonlinear spatial resonance response of a real thin shell structure.

86-2228
Modal Analysis of a Shell-Payload Structure Using Test Data
T.G. Carne, D.R. Martinez, M.D. Tucker, J.P. Lauffer
Sandia National Labs., Albuquerque, NM
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 646-655, 9 figs, 3 tables, 11 refs

KEY WORDS: Shells, Experimental modal analysis, Natural frequencies

This study evaluates the accuracy of computed modal frequencies obtained from a combined experimental/analytical model for a shell-payload structure. The total structure is physically divided into two subsystems, the shell and the internal payload, which are connected through a stiff joint. The payload was tested to obtain its free modes, while a finite element model of the shell was analyzed to obtain its modal description. A component mode synthesis technique was investigated which incorporates free modes and residual flexibility. The experimental modal data base for the payload was directly coupled with the finite element modal model of the shell to create an experimental/analytical model of the total structure. Both the translational and rotational elements of the payload mode shapes at the interface were measured and used in the coupling. The modal frequencies, computed using the combined experimental/analytical model, were then compared to those from a modal test of the entire structure. Recommended procedures for developing combined experimental/analytical models of shell-payload structures are given.

86-2229
Steady State Response of an Internally Damped Spherical Shell Translationally or Rotationally Driven at an Edge
T. Irie, Y. Kobayashi
Hokkaido Univ., Sapporo, Japan
J. Sound Vib., 105 (3), pp 491-502 (Mar 22, 1986) 10 figs, 1 table, 14 refs

KEY WORDS: Spherical shells, Internal damping, Resonant frequencies, Mode shapes, Transfer matrix method

The steady state response of an internally damped spherical shell translationally or rotationally driven at an edge is determined by the transfer matrix analysis method. For this purpose, the applicability of the thin shell theory is assumed and the governing equations of vibration of the shell are written as a coupled set of first order differential equations by using the transfer matrix of the shell. Once the transfer matrix has been determined by quadrature of the equations, the steady state response is calculated numerically together with the natural frequencies in terms of the elements of the transfer matrix of the shell under any combination of boundary conditions. By the application of the method, the dynamic responses and the resonant frequencies are calculated numerically for shells driven by sinusoidally varying axial, transverse deflection, or angular rotation at an edge.

86-2230
The Computation of the Dynamic Response of Cylindrical Shells in a Turbulent Flow
J. Horacek
Czechoslovak Academy of Sciences, Prague, Czechoslovakia
Acta Technica CSAV, 31 (2), pp 214-229 (1986) 5 figs, 9 refs

KEY WORDS: Cylindrical shells, Fluid-induced excitation, Turbulence

The normal mode approach is used for the estimation of the random dynamic response of a closed, simply supported cylindrical shell in or with axially flowing fluid. The shell is subjected to the pressure fluctuations beneath the developed turbulent boundary layer and to the static prestress. The Goldenveizer-Novozhilov theory of thin shells is considered. The derived formulas for the computation of the power spectral densities and the variancies of the radial displacement of shell are discussed and illustrated by means of the numerical examples.

86-2231
Non-Axisymmetric Impact Loading of a Thick Hollow Cylinder
R. Brepta
Czechoslovak Academy of Sciences, Prague, Czechoslovakia
Acta Technica CSAV, 31 (2), pp 149-176 (1986) 6 figs, 7 refs

KEY WORDS: Cylindrical shells, Impact response

The article contains the theoretical solution of impact stress field caused by a single force acting from outside of a thick hollow cylinder (thick shell). This asymmetric dynamic loading is solved by the elastodynamic theory of small strains. The problem is considered as a two-dimensional plane strain. Relations for displacements and stress components are also developed.

86-2232
Exact Solutions for the Free Vibrations of Open Cylindrical Shells with Circumferentially Varying Curvature and Thickness
K. Suzuki, A.W. Leissa
Yamagata University, Yonezawa, Japan
J. Sound Vib., 107 (1), pp 1-15 (May 22, 1986) 9 figs, 2 tables, 9 refs

KEY WORDS: Cylindrical shells, Variable cross section, Natural frequencies, Mode shapes

An exact solution procedure is developed to determine the free vibration frequencies and mode shapes of open noncircular cylindrical shells having circumferentially varying thickness and two opposite, curved edges supported by shear diaphragms. The remaining two edges, which are straight line segments parallel to the shell generators, may have arbitrary boundary conditions. The method is demonstrated for shells having elliptical cylindrical curvature and a thickness which varies quadratically in the circumferential direction, and straight edges which are clamped. For this symmetric configuration, vibration modes separate into symmetric and antisymmetric classes, and the exact frequencies are the roots of fourth order determinants. Numerical results are given showing the variations of frequencies and mode shapes of both symmetry classes with the shell length.

86-2233
Stability of Cylindrical Shells Subjected to Random Loadings
G. Ahmadi
Clarkson Univ., Potsdam, NY
J. Sound Vib., 107 (1), pp 83-95 (May 22, 1986) 2 figs, 53 refs

KEY WORDS: Cylindrical shells, Donnell's theory, Seismic excitation

The definitions of almost-sure stability and mean-square stability and the corresponding stability theorems are presented. The dynamics of a cylindrical shell according to Donnell's linear theory is considered and several criteria for the stability of the equilibrium state of the shell are established. Several special cases of stationary, nonstationary, white and nonwhite

random loadings are considered. The stability of cylindrical shells during earthquake strong motions is briefly discussed.

86-2234
A Study on the Vibration and Sound of Bells with Slight Asymmetry
Y.-H. Yum, J.M. Lee, S.H. Kim
Seoul National Univ., Seoul, Korea
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 75-80, 10 figs, 6 tables, 9 refs

KEY WORDS: Structural modification techniques, Bells, Finite element technique, Experimental modal analysis

Slight asymmetry exists in oriental bells due to decorative sculptures, carved figures, and casting irregularities and these asymmetries generate beat phenomenon, which is very important in acoustical properties of oriental bells. The influence of added symmetry to the bell on the beat frequencies and mode shapes is studied by using the finite element method and modal testing. Also efficient measurements of nodal lines and damping of bells with very small beat frequencies are discussed. A structure dynamic modification scheme is proposed to control beat frequencies and to determine the optimal striking position. Numerical analysis of the bell cavity is performed to investigate cavity resonance.

86-2235
Modal Test of Propellant Tank
S. Pazargadi
Wyle Labs., Norco, CA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 21-23, 4 figs, 1 table

KEY WORDS: Experimental modal analysis, Propellant tanks, Fluid-filled containers, Case histories

A fuel-filled propellant tank was subjected to a single shaker random excitation in the frequency range of 10 to 380 Hz. Due to the schedule and practical limitations the only information available on the input excitation was the shaker acceleration. Because of this limitation, transfer functions had to be developed from the acceleration ratio. Due to the coupling effects of the liquid and the test fixture to the shake table, the input frequency spectrum was not flat over the frequency range of the test. This created a number of large nonmodal peaks which needed more careful curve fitting strategy to identify the real modes.

PIPES AND TUBES

86-2236
An Advanced Multidimensional Method for Structural and Hydrodynamic Analysis of Liquid-Metal Fast Breeder Reactor Piping Systems
C.Y. Wang, W.R. Zeuch
Argonne National Lab., Argonne, IL
Nucl. Sci. Engrg., 92 (1), pp 170-177 (Jan 1986) 16 figs, 7 refs

KEY WORDS: Pipelines, Nuclear reactor component, Hydrodynamic response, Fluid-structure interaction

An advanced multidimensional method for structural and hydrodynamic analysis of piping systems of liquid-metal fast breeder reactors under various accident loads is described. The method couples a two-dimensional finite difference hydrodynamic technique with a three-dimensional finite element structural dynamics program. In the analysis, an elbow hydrodynamic model has been developed to account for the effect of global elbow motion. Treatment is provided for calculating fluid motion in the vicinity of the isolated flow region, rigid obstacle, and baffle plates, which commonly occurs in the in-line components. Also, an implicit time-integration scheme has been developed for structural analysis under long-duration accident loads. Three sample problems are given dealing with analyses of multidimensional fluid-structure interaction, hydrodynamics in the in-line components, and seismic response of a pipe-elbow loop.

86-2237
Effect of Internal Overpressure on Free Spanning Pipelines
G. Moe, H.S. Hansen, T. Overvik
The Norwegian Institute of Technology, Trondheim, Norway
Ocean Engrg., 13 (2), pp 195-207 (1986) 6 figs, 2 refs

KEY WORDS: Off-shore structures, Pipelines, Underwater structures, Natural frequencies

There is considerable uncertainty concerning the loading mechanism of offshore pipeline spans. The paper deals with the determination of the natural frequencies of a pipeline in a free span.

86-2238
Dynamic Stability of Pipes Conveying Pulsating Fluid
S.T. Ariaratnam, N.S. Namachchivaya

University of Waterloo, Waterloo, Ontario, Canada
J. Sound Vib., 107 (2), pp 215-230 (June 8, 1986) 6 figs, 16 refs

KEY WORDS: Pipes, Fluid-filled containers, Fluid-induced excitation

The dynamic stability of supported cylindrical pipes conveying fluid, when the flow velocity is harmonically perturbed about a constant mean value, is considered. Explicit stability conditions for perturbations of small intensity are obtained by using the method of averaging. For large periodic excitation a numerical method based on the Floquet theory is used to extend the stability boundaries. The effects of the mean flow velocity, dissipative forces, boundary conditions, and virtual mass on the extent of the parametric instability regions are discussed.

86-2239
Seismic Analysis of Multi-Span Piping
B. Lashkari, A. Karamchandani
Jack R. Benjamin & Assoc., Inc., Mountain View, CA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 151-159, 11 figs, 5 tables, 2 refs

KEY WORDS: Pipelines, Seismic response, Beams, Modal analysis

This paper describes two case studies of typical multi-span pipelines (with equal spans) in a large industrial facility. In each case, the stresses in the pipes due to horizontal seismic load are computed using both conventional approximate methods as well as a more accurate finite-element approach. Results of the study show that the approximate techniques can err both on the conservative side as well as the unconservative side and the magnitude of error can exceed a factor of 6.0. To help develop a better approach, the effects of factors, such as number of spans, end restraints, and pipe diameter are studied. This leads to development of models of simply-supported single-span beams with equivalent lengths which encompass the behavior of the multi-span pipes. These bounding models are then used to develop an approximate analysis approach which is usually conservative with much lower errors than the conventional approach. The proposed approach requires marginally more computations than the conventional approach.

86-2240
An Improved Technique for Snapback Excitation Using Multiple Force Inputs
K.W. Hunter, Sr., C.M. Linton, P.A. March
Tennessee Technological Univ., Cookeville, TN
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 160-166, 13 figs, 2 tables, 2 refs

KEY WORDS: Experimental modal analysis, Excitation techniques, Pipelines

This paper discussed an improved technique for snapback excitation that uses multiple static force inputs to individually excite the various modes of a test structure. The forces are applied such that the deformed shape of the structure approximates some mode shape of interest. When the multiple forces are simultaneously released, the desired mode dominates the free response of the structure. A series of tests was conducted on an eight-inch diameter piping system to evaluate the improved technique. The required static deflections for the first three horizontal modes of the piping system were obtained from the results of an experimental modal analysis using impact excitation. Simultaneous release of all input forces was achieved with the use of explosive bolt release devices. Modal amplitudes, natural frequencies, and modal damping values were derived from free-response displacement data by using a simplex algorithm to fit the data with a multiple degree-of-freedom, time-domain model.

86-2241
The Application of Lagrangian and Updated Lagrangian Formulations to Pipe Whip Problems
M.S. Gadala, M. Abo-Elkhier, M.M. Elmadany
Ontario Hydro Research, Toronto, Ontario, Canada
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 773-780, 6 figs, 35 refs

KEY WORDS: Lagrange equations, Pipelines, Pipe whip, Fluid-induced excitation, Modal analysis

The problem of pipe-whip is an important problem in the analysis of pipe lines carrying high energy/high pressure fluids. In this paper, a Lagrangian formulation (LF) and an updated Lagrangian formulation (ULF) for analysis of general geometric and material nonlinearity problems are outlined. The basic differences between the presented formulations and existing ones in the literature are discussed. Both LF and ULF are then applied to pipe-whip analysis. To simulate the shell effect of the pipe, it is modeled as a three-node isoparametric pipe-beam element. Results are presented for both displacement and velocity time histories. The results are compared with similar ones obtained from the ADINA general purpose finite element

program. The effect of various nonlinear terms, in the final equilibrium equations, on the number of increments is then investigated.

86-2242
Determination of Structural Damping in Straight Piping Sections Using Modal Analysis
A.G. Ware, G.L. Thinnes, J.G. Arendts
EG&G Idaho, Inc., Idaho Falls, ID
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 14-20, 9 figs, 1 table, 5 refs

KEY WORDS: Experimental modal analysis, Pipes, Damping coefficients, Case histories

Three- and eight-inch diameter pipes, supported rigidly at the ends and at intermediate points by typical piping supports, were excited to assess structural damping. Vibration sources for the 10 m (33 ft) lengths were an overhead crane (for snapback motion), impact hammer, and hydraulic shaker. Responses were measured by accelerometers, strain gauges, and an LVDT. Damping was calculated using complex-exponential curve fit (with commercial software), half-power, and logarithmic decrement methods. The paper details the test setup and steps taken to attain satisfactory coherence for the shaker frequency-response-functions. The relative merits of each type of instrumentation and computational technique for this application are discussed.

86-2243
Structural Damping Calculations of a Laboratory Piping System Using Modal Analysis
J.G. Arendts, A.G. Ware
EG&G Idaho, Inc., Idaho Falls, ID
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 257-263, 12 figs, 4 refs

KEY WORDS: Case histories, Pipelines, Damping coefficients, Modal analysis

The United States Nuclear Regulatory Commission and the Electric Power Research Institute have jointly sponsored construction of two laboratory piping systems for a variety of vibration research projects. The responses of these systems have been used to obtain piping system damping data considering different supports, methods of excitation, and calculations techniques. The 6-inch carbon steel systems were approximately fifty feet in length and were excited via impulse, simulated earthquake, random and swept sine types of input motion. Data were reduced for the modes in the seismic range (0 to 33 Hz). The system damping decreased as response frequency increased and generally consistent values were computed from the different types of tests conducted.

86-2244
Parameter Adjustment of a Finite Element Model by Means of Measured Natural Frequencies
F. Steinwender, R. Nordmann
Kraftwerk Union AG, Offenbach, Fed. Rep. Germany
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 795-801, 8 figs, 2 refs

KEY WORDS: Pipelines, Supports, Finite element technique, Natural frequencies, Structural modification techniques

To get better information about the dynamic characteristics of a piping support, particularly for the stiffness coefficients of the concrete steel-plate area and the warping effect in the post of the support, laboratory tests and corresponding finite element calculations were accomplished. An adjustment procedure has been applied to fit the uncertain stiffness parameters of the finite element model, requiring that the squared differences between calculated and measured natural frequencies become a minimum. The paper describes the employed procedure and presents results of the improved finite element model parameters.

86-2245
A Finite Element Computation of the Flow-Induced Oscillations in a Cantilevered Tube
W.S. Edelstein, S.S. Chen, J.A. Jendrzejczyk
Argonne National Lab., Argonne, IL
J. Sound Vib., 107 (1), pp 121-129 (May 22, 1986) 4 figs, 12 refs

KEY WORDS: Tubes, Cantilevers, Fluid-filled containers, Fluid-induced excitation, Finite element technique

A numerical method is presented for predicting the response of a cantilevered tube conveying fluid. Emphasis is placed on the oscillation amplitude, dominant frequency, and response mode shapes for flow velocities larger than the critical value. Numerical results and experimental data agree reasonably well.

86-2246
Estimate Exchanger Vibration
C.D. Nieh, H. Zengyan

Tianjin Univ., Tianjin, China
Hydrocarbon Processing, 65 (4), pp 61-65 (Apr 1986) 7 figs, 8 tables, 10 refs

KEY WORDS: Tubes, Heat exchangers, Fluid-induced excitation, Natural frequencies

A better method for determining resonant frequencies of exchanger tubing which provides operating and design flexibility without sacrificing reliability is presented.

86-2247
Structural Dynamics and Fluid Flow in Shell-and-Tube Heat Exchangers. Summary and Overview of a DOE/ECUT-Sponsored Research Program
M.W. Wambsganss, H. Halle, T.M. Mulcahy
Argonne National Lab., Argonne, IL
Rept No. ANL-85-76, 79 pp (Dec 1985) DE86007798/GAR

KEY WORDS: Shells, Tubes, Heat exchangers, Fluid-induced excitation

Objective of the research program is to contribute to the design and development of energy-efficient, reliable, and cost-competitive industrial shell-and-tube heat exchangers. This report highlights the many technical contributions of the DOE/ECUT-sponsored program, reviews industry's use of the program results, and identifies research needs. Vibration excitation mechanisms, fluid/structure coupling, and flow distribution are briefly reviewed to provide background information.

DUCTS

86-2248
Non-Linear Effects in Finite Amplitude Wave Propagation Through Ducts and Nozzles
M. Salikuddin, W.H. Brown
Lockheed-Georgia Company, Marietta, GA
J. Sound Vib., 106 (1), pp 71-106 (Apr 8, 1986) 41 figs, 29 refs

KEY WORDS: Ducts, Nozzles, Wave propagation, Sound waves, Nonlinear theories

An extensive study of nonlinear effects in finite amplitude wave propagation through ducts and nozzles is summarized. Some results from earlier studies are included to illustrate the nonlinear effects on the transmission characteristics of duct and nozzle terminations. Investigations, both experimental and analytical, were carried out to determine the magnitudes of the effects for high intensity pulse propagation. The results derived from these investigations are presented.

86-2249
Sound Radiation from Ducts: Theory and Experiment
M.A. Hamdi, J.M. Ville
Universite de Technologie de Compiegne, Cedex, France
J. Sound Vib., 107 (2), pp 231-242 (June 8, 1986) 10 figs, 13 refs

KEY WORDS: Ducts, Sound waves, Wave propagation

The paper deals with a method of prediction of noise radiated from finite length ducts with arbitrary shape. The computation of the internal and external acoustic field is based upon a new variational formulation by integral equations. Numerical results of far and near field radiation patterns are compared with experimental data for various higher order mode source conditions.

86-2250
Experimental Determination of the Reflection Coefficient of a Premixed Flame in a Duct
T. Poinsot, C. LeChatelier, S.M. Candel, E. Esposito
Ecole Centrale des Arts et Manufactures, Chatenay-Malabry, France
J. Sound Vib., 107 (2), pp 265-278 (June 8, 1986) 9 figs, 2 tables, 17 refs

KEY WORDS: Ducts, Combustion noise

In many situations, combustion instabilities involve a coupling between the nonsteady combustion process and the acoustic modes of the combustor system. Useful information on this coupling may be obtained by measuring the reflection response of the flame to incident acoustic perturbations. This measurement may be performed with a modified impedance tube set-up described in this paper. The method is illustrated with an application to a turbulent premixed combustor. It is found that large values of the reflection response are obtained when the flame approaches the limit of instability. The frequency corresponding to the maximum response is also close to that characterizing the instability regime. It is suggested that the measurement of the reflection response may constitute a valuable diagnostic for the prediction of combustion instability.

86-2251
Nonisentropic Propagation of Sound in Uniform Ducts Using Euler Equations
R.S. Goonetilleke, S.G. Lekoudis, W.C. Strahle
Georgia Institute of Technology, Atlanta, GA
AIAA J., 24 (7), pp 1088-1094 (July 1986) 6 figs, 1 table, 17 refs

KEY WORDS: Ducts, Sound waves, Wave propagation

The problem of sound propagation in uniform ducts is examined using the Euler equations. A numerical spatial marching technique is examined for the case of no mean flow. The technique uses an initial value formulation. It is found that the scheme is stability limited, in agreement with previous results obtained using the Helmholtz equation. Duct mode analysis is also performed.

86-2252
Noise Breakout from Flat-Oval Ducts
A. Cummings, I.-J. Chang
Univ. of Missouri, Rolla, MO
J. Sound Vib., 106 (1), pp 17-33 (Apr 8, 1986) 10 figs, 9 refs

KEY WORDS: Ducts, Sound waves, Wave propagation

Two theoretical treatments concerning the transmission of internally propagated sound at low frequencies through the walls of flat-oval ducts are described. One of these is based on a numerical solution to the equations of motion for the duct walls, and the other on a forced wave duct wall response to the internal sound field. Only the plane internal acoustic mode is considered. Both theories are in reasonable agreement with experimental data at low frequencies, though discrepancies are noted in the region where higher order acoustic modes can propagate within the duct.

86-2253
A Modal Analysis Approach to Combustion Driven Oscillations
D.J. Kato, R.A. Knepper
Onan Corp., Minneapolis, MN
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 506-510, 10 figs, 3 refs

KEY WORDS: Modal analysis, Combustion excitation, Ducts, Noise generation, Vibration control

A major oil refinery experienced severe vibration and noise problems with a number of its forced draft heaters. The sound was characterized by extremely loud low frequency tones. The vibrations were so severe that the rectangular ductwork would routinely crack and would need to be rewelded at the corners. An applied research effort was undertaken to find a general feasible solution to the problem. Modal analysis of the heater ductwork revealed natural modes of vibration that were identical in frequency to the tones in the sound spectra of the fired heaters. It was determined that these modes were driven to a resonant condition by the combustion process itself which ultimately caused the failure . The final recommendation was to apply a constrained layer damping system to the heater ductwork. This approach was tried on fired heaters and worked remarkably well.

ELECTRIC COMPONENTS

CONTROLS (SWITCHES, CIRCUIT BREAKERS)

86-2254
Dynamic Behavior of a Hydraulically Actuated Mechanism. Part 1: Small Perturbations
V. Venkatraman, R.W. Mayne
State Univ. of New York, Buffalo, NY
J. Mech., Transm., Autom. in Des., 108 (2), PP 245-249 (June 1986) 5 figs, 14 refs

KEY WORDS: Actuators, Hydraulic servomechanisms, Transient response

The dynamic behavior of a mechanism actuated by an oscillating hydraulic cylinder is considered. The analysis is generalized by introducing nondimensional parameters. Linearization is applied to explore the basic nature of the system transient response. A wide range of parameter values is considered to illustrate the effects of fluid capacitance, fluid inertance, load, leakage and friction on the system behavior and quantitative design guidelines are indicated.

86-2255
Dynamic Behavior of a Hydraulically Actuated Mechanism. Part 2: Nonlinear Character
V. Venkatraman, R.W. Mayne
HMT Limited, Hyderabad, India
J. Mech., Transm. Autom. in Des., Trans. ASME, 108 (2), pp 250-254 (June 1986) 7 figs, 2 refs

KEY WORDS: Actuators, Hydraulic servomechanisms, Nonlinear response

The first of these papers considering a hydraulically actuated mechanism presents the common oscillating cylinder arrangement and sets of equations which describe the dynamic system. It then defines dimensionless groups that characterize the actuator-mechanism and explores the quasi-linear behavior of the system. This present paper focuses on the nonlinear nature of the system. Effects of transmission angle, mechanism geometry and loading are considered as well as the range of operation in which the small perturbation behavior provides an adequate description of the dynamic response. A new parameter which plays an important role in characterizing the dependence of the system transient response on mechanism geometry is identified.

ELECTRONIC COMPONENTS

86-2256
Source Identification on a Digital Computer Using Acoustic Intensity
A. Chawla, N. Popplewell
Sperry Inc., Winnipeg, Manitoba, Canada
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 520-525, 4 figs, 1 table, 9 refs

KEY WORDS: Noise source identification, Acoustic intensity method, Computer systems hardware

This paper deals with the identification of the principal sound radiation regions of a digital computer by using the acoustic intensity technique. The contribution of the airflow (within the computer) to the overall noise levels is also discussed.

86-2257
Application of Finite Element Analysis, Component Mode Synthesis and Modal Test Data in the Development of Rotary Actuators in High Performance, 5.25 Inch Winchester Disk Drives
D. Fields, L. Gollbach, R. Stromsta
Vertex Peripherals, Milpitas, CA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 334-341, 8 figs, 1 table, 5 refs

KEY WORDS: Linking analysis and test, Experimental modal analysis, Component mode synthesis, Disk drives, Finite element technique

MSC-NASTRAN and PATRAN-G along with an APOLLO 660 engineering work station was used to successfully integrate finite element analysis with the design cycle in the development of rotary actuators. A review of the modeling effort in the V100 series actuator is presented. The use of MSC-NASTRAN in modeling the 3370 load beam is given. From the solution for one 3370 recording load beam, component mode synthesis was used to replicate the load beams and solve for the normal modes of the actuator/load beam structural system. The comparison of experimentally measured mode shapes along with computed mode shapes is excellent up to 3000 HZ. The comparison of the computed open loop mechanical transfer functions along with experimental data is also presented.

86-2258
Experimental Modal Analysis and Disc Drive Noise Reduction: A Case History
J. Castagna
Priam Corp., San Jose, CA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 501-505, 12 figs

KEY WORDS: Experimental modal analysis, Disk drives, Case histories, Noise reduction

New generation advanced disc drives, noted for the high capacity storage they provide, are being applied in new environments that are placing conflicting demands on the mechanical hardware. A case history is presented using modal analysis; in the form of normal mode identification and running mode studies to identify behavior of the major components of the entire system and to evaluate the proposed alternatives to reduce noise output to an acceptable level. Closely spaced modes of several components complicated the analysis; some of the methods used to identify the noise source are discussed.

DYNAMIC ENVIRONMENT

ACOUSTIC EXCITATION

86-2259
The Role of Screech Tones in Mixing of an Underexpanded Rectangular Jet
A. Krothapalli, Y. Hsia, D. Baganoff, K. Karamcheti
Stanford Univ., Stanford, CA
J. Sound Vib., 106 (1), pp 119-143 (Apr 8, 1986)
24 figs, 1 table, 23 refs

KEY WORDS: Nozzles, Jet noise

An experimental investigation has been carried out on an underexpanded jet of air issuing from a converging rectangular nozzle of moderate aspect ratio. Schlieren pictures of the flow field along with hot-wire measurements in the jet were obtained at different pressure ratios. At the pressure ratio corresponding to the maximum screeching sound, Schlieren photographs show a very strong organized cylindrical wave pattern on either side of the jet, with their respective sources being located at the end of the third shock cell. Associated with this wave pattern is a large increase in the angle of spread of the jet. It is shown that the self-excitation helps to induce large scale vortical motions in the jet both in the plane containing the small dimension of the nozzle and in the plane containing the long dimension of the nozzle.

86-2260
Absorption Cross Section of Absorber Cylinders
F.P. Mechel
Fraunhofer-Institut fur Bauphysik, Stuttgart, Fed. Rep. Germany
J. Sound Vib., 107 (1), pp 131-148 (May 22, 1986) 19 figs, 1 table, 7 refs

KEY WORDS: Acoustic absorption, Cylinders, Porous materials

The paper covers derivation and calculation of absorption and scattering cross sections of three types of cylinders made out of porous absorber material. These types are, respectively, completely bulk reacting (homogeneous and isotropic), axially locally reacting but bulk reacting about the circumference (rigid partitions inserted normal to the cylinder's axis), and, locally reacting in all directions. The sound field may be either plane waves with oblique incidence or diffuse sound fields. The characteristic data used for the absorber materials, propagation constant and wave impedance, are in the form of simple approximations taken from a model theory of fibrous absorbers for low frequencies, with experimental data being used at medium and high frequencies. A formulation of the scattered sound field in series of Bessel functions is used. The numerical results show the influence of the frequency, the diameter, the materials' flow resistance and the angle of incidence.

86-2261
Sound Transmission Through Double Partitions with Cavity Absorption
A. Trochidis, A. Kalaroutis
Univ. of Thessaloniki, Thessaloniki, Greece
J. Sound Vib., 107 (2), pp 321-327 (June 8, 1986) 3 figs, 7 refs

KEY WORDS: Acoustic absorption, Sound waves, Wave transmission, Walls

The sound transmission through double partitions with cavity absorption is discussed. A simple model is considered, consisting of two parallel thin elastic plates containing sound-absorbing material in the cavity between them. An expression for the transmission loss is obtained and calculations carried out for representative examples are compared with existing experimental values. The agreement in all cases is good.

86-2262
Laser-Doppler Measurement of Complex Acoustic Impedance
M.R. Davis, K.J. Hews-Taylor
Univ. of Tasmania, Tasmania, Australia
J. Sound Vib., 107 (3), pp 451-470 (June 22, 1986) 13 figs, 4 tables, 8 refs

KEY WORDS: Acoustic impedance, Laser-Doppler method

A laser-Doppler anemometer is used to sense fluctuating acoustic velocity and a microphone to sense the pressure. The pressure and Doppler signals are multiplied so that under pure tone acoustic excitation the resulting signal spectrum has asymmetric sidebands. Analysis of such spectra makes possible the determination of both magnitude and phase of the fluctuating particle velocity with respect to the microphone signal. It is found that the standard errors introduced by the analysis of the spectra are 0·06 dB in amplitude and 1° in phase angle.

86-2263
Predicting Sound Power Radiation from Built-Up Structures Using Statistical Energy Analysis
G.J. Stimpson, J.C. Sun, E.J. Richards
Univ. of Southampton, Southampton, England
J. Sound Vib., 107 (1), pp 107-120 (May 22, 1986) 6 figs, 15 refs

KEY WORDS: Sound waves, Wave radiation, Machinery noise, Statistical energy methods

Statistical energy analysis methods have been used in conjunction with energy accountancy ideas to develop a technique for the prediction of sound power radiation from machinery and other built-up structures. The methods enable calculation and optimization of the changes in noise radiation associated with modifications to individual parts of a coupled structure. As an initial exercise the techniques have been applied to predict the noise radiation from a coupled

system composed of two plates welded at right angles. The predicted noise radiation is compared with values obtained from direct measurements by the surface velocity technique and agreement generally within 2 or 3 dB on overall level is obtained.

86-2264
A Pulsed Harmonic Technique for the Study of Sound Propagation in the Atmosphere
D.A. Bohlender, F. Babott, P.J. Irwin, T. Mathews
Univ. of Calgary, Calgary, Alberta, Canada
J. Sound Vib., 105 (*2), pp 283-290 (Mar 8, 1986) 6 figs, 19 refs

KEY WORDS: Sound waves, Wave propagation, Measuring instrumentation

A description of equipment used in the study of sound propagation in the atmosphere near the Earth's surface is given. The effective flow resistivity of the ground was determined by a best fit of measured sound levels near the surface 50 m from a source to theoretical levels, calculated by using a partially coherent acoustics theory and empirical relations of Delany and Bazley. This in turn permitted calculation of the theoretical sound levels at greater ranges for comparison with measured values. Results for a plowed field and a snow-covered field are presented.

86-2265
The Practical Assessment of Errors in Sound Intensity Measurement
P.S. Watkinson
Plessey Marine, Templecombe, England
J. Sound Vib., 105 (2), pp 255-263 (Mar 8, 1986) 7 figs, 14 refs

KEY WORDS: Acoustic intensity method, Measurement techniques, Error analysis

Errors in two transducer sound intensity measurements are difficult to assess in practical situations, but two in particular can be calculated. These are the error associated with phase mis-match and random error. The use of the known phase mis-match is discussed regarding its use in evaluating the quality of a particular measurement, and the use of coherence is discussed considering its use in calculating random error.

86-2266
Sound Propagation in a Flat-Oval Waveguide
A. Cummings, I.-J. Chang
Univ. of Missouri, Rolla, MO
J. Sound Vib., 106 (1), pp 35-43 (Apr 8, 1986) 5 figs, 1 table, 2 refs

KEY WORDS: Waveguides, Sound waves, Wave propagation

A numerical method for finding the eigenvalues and eigenfunctions associated with acoustic propagation in a uniform waveguide of flat-oval cross-section is described. Comparison is made between the numerical results and experimental data, and the agreement is generally satisfactory. The method described should be of use in calculating the sound transmission loss of the walls of flat-oval air conditioning ductwork.

86-2267
Some Simple and Effective Methods for Sound Source Identification with Geometrical Acoustic Models
E. Luzzato, C. Lecointre
Direction des Etudes et Recherches de l' E.D.F., Cedex, France
J. Sound Vib., 105 (3), pp 473-490 (Mar 22, 1986) 8 figs, 1 table, 7 refs

KEY WORDS: Noise source identification, Numerical methods

The theoretical problem of sound source identification in an enclosed space is solved by minimizing a positive definite functional which is expressed in terms of the distance between the space distributions of the measured and the calculated acoustic pressures in a domain of the space. Two numerical methods for sound source identification are presented, it being assumed that the acoustic propagation in the space can be represented by geometrical acoustic models. The first method is used to determine the acoustic power of geometrically distinct, point-like sources, the reverberant sound field being assumed to be almost uniform. The second method, based on geometric acoustics ray theory, is designed for large scale sources which may generate non-uniform reverberant fields. For each method, an illustrative example is presented and the calculated acoustic powers are compared to measured ones.

SHOCK EXCITATION

86-2268
Implementation of a Preprocessor for a Shock Wave Loading
J. Vanbeest

Technische Hogeschool Delft, Netherlands
Rept. No. B8575342, 18 pp (Dec 1985) N86-20748/7/GAR

KEY WORDS: Shock Waves, Computer program, Explosion effects

Determination of explosion shock wave loading on a structure in the ICES-STRUDL program is outlined. Assuming that the peak overpressure, the duration of the positive phase, and the direction of the shock wave are known, the overpressure at any point of the structure may be determined using the shock wave loading.

86-2269
Modal Synthesis of Components with Gaps
Shi-Jin Zhu
Nanjing Aeronautical Institute, Nanjing, China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 264-269, 4 figs, 1 table, 8 refs

KEY WORDS: Modal analysis, Vibro-impact systems, Modal synthesis

A modal synthesis technique is used to calculate the vibro-impact problems of real machine parts or structure systems, within which there are gaps existing between components. The author gives up the overly simplified impact spring model which is commonly used, and suggests the idea of impact modes, as well as conditional compatibility relations in order to be able to study more cases including two extreme cases. A coupled but reduced nonlinear dynamic equation, with or without considering damping, is finally obtained in matrix form. The vibro-impact response problems, as well as free vibration of these systems, can be numerically calculated.

VIBRATION EXCITATION

86-2270
Solution of Large Unsymmetric Eigensystems for Fluid/Structure Interaction Problems
I.-W. Yu
Westinghouse Research and Development Center, Pittsburgh, PA
Nuclear Sci. and Engrg., 92, pp 157-161 (Jan 1986) 7 figs, 1 table, 6 refs

KEY WORDS: Fluid-structure interaction, Finite element technique

The finite element solution of fluid/structure interaction problems is considered for a class of acousto-elastic problems where the fluid is linear acoustic and the structure is linear elastic. The finite element formulation in terms of fluid pressure and structural displacement results in a system of unsymmetric equations. The use of the subspace iteration method, in conjunction with the QZ algorithm, can by used for solving large fluid/structure systems. The computational procedure is similar to that for the real symmetric case, and the procedure can easily be adopted by any finite element code.

86-2271
Airfoil Gust Response and the Sound Produced by Airfoil-Vortex Interaction
R.K. Amiet
United Technologies Research Center, East Hartford, CT
J. Sound Vib., 107 (3), pp 487-506 (June 22, 1986) 10 figs, 25 refs

KEY WORDS: Airfoils, Wind-induced excitation, Sound generation, Fluid-induced excitation

This paper contributes to the understanding of the noise generation process of an airfoil encountering an unsteady upwash. By using a fast Fourier transform together with accurate airfoil response functions, the lift-time waveform for an airfoil encountering a delta function gust (the indicial function) is calculated for a flat plate airfoil in a compressible flow. This shows the interesting property that the lift is constant until the generated acoustic wave reaches the trailing edge. Expressions are given for the magnitude of this constant and for the pressure distribution on the airfoil during this time interval. The case of an airfoil cutting through a line vortex is also analyzed.

86-2272
Analysis of Spurious Eigenmodes in Finite Element Equations
S. Bates, B. Cathers
Manchester Univ., Manchester, UK
Intl. J. Numer. Methods Engrg., 23 (6), pp 1131-1143 (June 1986) 7 figs, 6 refs

KEY WORDS: Normal modes, Finite element technique

Numerical analysis of difference schemes often reveals the presence of eigenmodes which do not feature in the continuum solution. An examination of the dispersion relation shows how the spurious and physical modes interact. The behavior of certain wave-profiles was predicted using this analysis and the results confirmed by numerical experiment.

86-2273
Steady State Response of Undamped Systems to Excitations Expressed as Polynomials in Time
A.Y.T. Leung
Univ. of Hong Kong, Hong Kong
J. Sound Vib., 106 (1), pp 145-151 (Apr 8, 1986) 3 figs, 2 refs

KEY WORDS: Periodic response, Undamped structures, Modal analysis, Duhamel integral

An excitation, if expressed as a polynomial in time, a particular integral of the governing partial differential equation of an undamped continuous system may be assumed to be polynomial as well. This provides an alternative to the traditional use of the Duhamel integral. The particular integral in polynomial form is the steady state response corresponding to the polynomial excitation acting on the system. Only frequency independent stiffness and mass matrices are required to solve for the steady state exactly. Transients can be included by modal analysis. Recurrent formulae for piecewise linear and cubic forcing functions are given explicitly.

86-2274
Forces Vibration and Wave Propagation in Mono-Coupled Periodic Structures
M. Ohlrich
Technical Univ. of Denmark, Lyngby, Denmark
J. Sound Vib., 107 (3), pp 411-434 (June 22, 1986) 13 figs, 1 table, 25 refs

KEY WORDS: Periodic structures, Forced vibration, Wave propagation, Mobility method

This paper describes the wave propagation and vibration characteristics of mono-coupled structures which are of a spatially periodic nature. The receptance approach to the periodic structure theory is applied to study undamped periodic systems with composite structural elements; particular emphasis is placed on investigation resonant periodic point loading and its pronounced effect on the propagation of longitudinal waves. General mono-coupled periodic systems are first assumed to be infinite in extent; thereafter reflections caused by arbitrary end terminations of finite structure are considered and a general closed form solution is found for the forced harmonic response at element junctions. This junction-receptance is used to determine discrete junction mode shapes of a finite system. The forced response of a finite structure with an internal obstruction is derived as a natural extension of the determination of the junction-receptance. The influence of such a disorder is illustrated by a simple example.

86-2275
The Response of Two-Degree-of-Freedom Systems with Quadratic Non-Linearities to a Combination Parametric Resonance
A.H. Nayfeh, L.D. Zavodney
Virginia Polytechnic Institute and State Univ., Blacksburg, VA
J. Sound Vib., 107 (2), pp 329-350 (June 8, 1986) 25 figs, 1 table, 11 refs

KEY WORDS: Parametric resonance, Tuning

The response of two-degree-of-freedom systems with quadratic nonlinearities to a combination parametric resonance in the presence of two-to-one internal resonance is investigated. The method of multiple scales is used to construct a first order uniform expansion yielding four first order nonlinear ordinary differential equations governing the modulation of the amplitudes and the phases of the two modes. Steady state responses and their stability are computed for selected values of the system parameters. The effects of detuning the internal resonance, detuning the parametric resonance, the phase and magnitude of the second mode parametric excitation, and the initial conditions are investigated. Some limit cycles are also shown to experience period doubling bifurcations. The perturbation solutions are verified by numerically integrating the governing differential equations.

86-2276
On Various Definitions of the Envelope of a Random Process
R.S. Langley
Cranfield Institute of Technology, Bedford, England
J. Sound Vib., 105 (3), pp 503-512 (Mar 22, 1986) 1 fig, 17 refs

KEY WORDS: Random vibrations

Statistical properties of the envelope definitions of Rice, Crandall and Mark, and Dugundji are derived and compared. It is shown that the definitions of Rice and Dugundji are equivalent, which implies that the envelope of Rice is independent of the choice of a central frequency. This contradicts results which have appeared in the literature and the reason for this contraction is explained. The envelopes of Crandall and Mark and Dugundji are found to have the same first order probability density function but different crossing rates and mean frequencies.

86-2277
The Prediction of the Vibration Characteristics of Robots
I.M. Howard, B.J. Stone

Univ. of Western Australia, Nedlands, Western Australia
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 342-348, 13 figs, 5 refs

KEY WORDS: Robots, Actuators, Linkages, Mobility method, Substructuring methods

A method of analyzing the vibration response of robotic structures is presented. The method employs the receptance technique, which allows a complex structure to be divided into simpler sub-systems. These sub-systems are then joined using the appropriate end conditions. The approach allows experimental and theoretical subsystems to be used so that the measured characteristics of hydraulic actuators and theoretical predictions of robotic linkage characteristics may be combined. The method is illustrated for a simple robot structure.

86-2278
On Wake-Induced Vibration of a Conductor in the Wake of Another Via a 3-D Finite Element Method
Y.T. Tsui
Hydro-Quebec Research Institute, Varennes, Quebec, Canada
J. Sound Vib., 107 (1), pp 39-58 (May 22, 1986) 4 figs, 11 refs

KEY WORDS: Transmission lines, Fluid-induced excitation

Bundled conductors exhibit a phenomenon known as wake-induced vibration, or, in power-line parlance, subspan vibration. The wake-induced vibration is caused by the steady aerodynamic force field, generated by the wake of the windward conductor, in which the leeward conductor lies. Two-dimensional formulations of this problem have been thoroughly studied. This problem is treated three-dimensionally via a finite element method. Discrepancies between 2-D and 3-D results lead one to question the validity of 2-D model representation for the 3-D physical reality. It remains to be seen whether or not the 3-D numerical results can be substantiated experimentally.

MECHANICAL PROPERTIES

DAMPING

86-2279
The Analysis of Hysteretic Systems with Reference to a Particular Model
H.R. Lo, M. Yar, J.K. Hammond
Univ. of Southampton, Southampton, England
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 730-735, 4 figs, 4 refs

KEY WORDS: Modal analysis, Hysteretic damping

Displacement relationships often exist in engineering structures and this paper is aimed at developing analytical and computational procedures related to a particular differential equation model of hysteresis. The model selected is quite general in the sense that various hysteretic characteristics may be obtained by adjusting the several parameters in the equation. A theoretical analysis of this system using the Volterra series approach is shown to be inadmissible because of the nonanalytic property of this model. An approach to alleviate this is to approximate the nonanalytic nature of the model and this is described. It is shown how a least squares optimization procedure may be used to fit this particular model to measured data. This is explored using simulation data.

86-2280
An Investigation of Nonlinear Damping Effects on Modal Analysis Results
D.J. Dimas, G.C. Pardoen, M. Mitchell-Dignan
PDA Engineering, Santa Ana, CA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 439-445, 8 figs, 4 tables, 10 refs

KEY WORDS: Modal analysis, Damping effects

The effects of well-defined nonlinearities on modal analysis results are investigated. These effects were accomplished by numerically integrating the equation of motion for a nonlinear 1 DOF system subjected to a series of harmonic forcing functions. The specific nonlinearity investigated was due to damping forces proportional to the powers of velocity other than one. This nonlinearity often occurs in mechanical systems in which objects move through fluids at moderate velocities. The analysis results for these systems with controlled nonlinear effects are displayed in a series of three-dimensional plots using state-of-the-art interactive graphics software (PDA/PATRAN).

86-2281
A Study on the Vibration Characteristics of Tennis Racket by Modal Analysis
Jae Eung Oh, Sung Ha Yum, You Yub Lee
Han Yang Univ., Seoul, Korea
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp pp 177-131, 6 figs, 2 tables, 3 refs

KEY WORDS: Experimental modal analysis, Tennis rackets, Damping coefficients

Air type and epoxy type rackets were compared to investigate the damping effect due to the existence and/or nonexistence of damping material, by examining its maximum bending moment and logarithmic decrement after impact between racket and ball. In order to clarify the dynamic behavior of the tennis racket, mode shapes corresponding to each natural frequency were obtained, and its sweet spot was determined by considering the node line at each natural frequency. The final modifications were applied to a new prototype and its dynamic behavior was checked by experimental modal analysis.

86-2282
Identification of Nth-Power Velocity Damping
J.E. Mottershead, R. Stanway
Univ. of Liverpool, Liverpool, England
J. Sound Vib., 105 (2), pp 309-319 (Mar 8, 1986)
3 tables,4 figs, 10 refs

KEY WORDS: Damping coefficients, Sinusoidal excitation, Parameter identification technique

This paper demonstrates how the two damping parameters associated with the nonlinear nth-power velocity model can be identified from the time series records of the displacement and velocity responses to sinusoidal excitation. No restriction is imposed on the level of damping present and estimates are acquired by minimizing the square of the error between observed responses and those predicted by a linearized model. The problems of noise contamination and uncertain initial conditions are treated by using simulated data and converged estimates are presented with computation times measured in CPU seconds on a VAX 11/780 computer.

86-2283
Damping in Beams and Plates Due to Slipping at the Support Boundaries
E.H. Dowell
Duke Univ., Durham, NC
J. Sound Vib., 105 (2), pp 243-253 (Mar 8, 1986)
1 fig, 11 refs

KEY WORDS: Coulomb friction, Beams, Plates

Dry friction damping due to axial sliding surfaces normal to the principal lateral direction of structural motion is studied. Primary emphasis is on sufficiently large motion that slipping occurs throughout a cycle. Beams with arbitrary support conditions and vibrating in an arbitrary mode are considered; also a pinned-pinned rectangular plate is studied. In all cases, a simple explicit formula is obtained for an equivalent, linear, viscous critical damping ratio.

86-2284
The Influence of Microslip on Vibratory Response, Part I: A New Microslip Model
C.-H. Menq, J. Bielak, J.H. Griffin
Carnegie-Mellon Univ., Pittsburgh, PA
J. Sound Vib., 107 (2), pp 279-293 (June 8, 1986) 15 figs, 20 refs

KEY WORDS: Coulomb friction, Damped structures

A new, physically motivated, continuous microslip model of friction is developed for analyzing the dynamic response of frictionally damped structures in which the friction interface is subjected to high normal loads. By using this model with a single-degree-of-freedom oscillator it is found that incorporating the effects of partial slip of the friction interface can result in significant reductions of the resonant response with respect to that of a system in which only gross slip is allowed.

86-2285
The Influence of Microslip on Vibratory Response, Part II: A Comparison with Experimental Results
C.-H. Menq, J.H. Griffin, J. Bielak
Carnegie-Mellon Univ., Pittsburgh, PA
J. Sound Vib., 107 (2), pp 295-307 (June 8, 1986) 13 figs, 14 refs

KEY WORDS: Coulomb friction, Damped structures

The influence of microslip on the resonant response of structures that are restrained by a friction contact is discussed. Microslip or partial slip of the friction interface becomes important and needs to be taken into account when the friction contact pressure is large. A new model of microslip is used in simulating the vibratory response of three sets of experiments; in each case partial slip of the friction interface resolves anomalies that could not be explained by the simple point contact model of friction that has been used in the past to analyze these types of problems.

86-2286
A Perturbation Method for Dynamic Analysis of Structures with Constrained Viscoelastic Layers
X.S. Cao, D.P. Dai, C.H. Ku

Xi'an Jiaotong Univ., China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 826-830, 3 figs, 5 tables, 7 refs

KEY WORDS: Layer damping, Viscoelastic damping

Techniques of structural vibration control by means of constrained viscoelastic layers have been widely applied. The shear modulus and loss factors of viscoelastic materials vary with frequency and have an important effect on resonance frequencies and damping factors of structures with constrained viscoelastic layers. It is generally impractical for analyzing the dynamic characteristics of large structural systems with the conventional finite element method. This paper presents a method to solve this problem. The method is based on perturbation of the eigensystem and the finite element model by using a displacement formulation based on the small deflection theory. The damped resonance frequencies and modal damping factors can be predicated in a wider frequency range without reanalysis of eigenproblems. The cost and size of analysis can be greatly reduced. A typical example is presented to demonstrate the validity of this method.

86-2287
The Application of Experimental Modal Analysis to Transmission Line Hardware
P. Bourdon, J. Brunelle, C. Hardy, P. Lavigne
Institut de recherche d'Hydro-Quebec, Varennes, Quebec, Canada
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 7-13, 23 figs, 5 tables, 3 refs

KEY WORDS: Experimental modal analysis, Dampers, Transmission lines, Case histories

Power transmission line dampers and spacer dampers are nonlinear devices. A method for defining their dynamic characteristics is presented. Using swept sine constant velocity excitation techniques at three pertinent levels, the technique of experimental modal analysis is successfully applied to extract modal models of these devices which fit generally well with measured data. Two types of single conductor Stockbridge type dampers and 2, 3, and 4 conductor spacer dampers are analyzed. Areas where the technique can be improved are identified.

86-2288
Dynamic Response of Non-Proportionally Damped Systems Using a Successive Transformation Technique
R. Greif, L. Wu
Tufts Univ., Medford, MA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 349-353, 6 figs, 9 refs

KEY WORDS: Damped structures, Successive transformation method, Substructuring methods

The dynamic response of systems with non-proportional damping is solved by a successive transformation method. This technique is based on the free interface modes in the physical coordinates followed by fixed interface modes in the generalized coordinates. It uses the state space (first order) form of the equations and accurately includes subsystems with rigid body motion. A 15-degree-of-freedom system is investigated and modal truncation effects are studied for steady state response and transient response.

FATIGUE

86-2289
Using Test and System Dynamic Analysis for Component Life Predictions
G.E. Townley, J.W. Klahs
Structural Dynamics Research Corp., Milford, OH
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 656-662, 8 figs, 2 tables, 4 refs

KEY WORDS: Fatigue life, Modal analysis, Military vehicles

A discussion of the combination of experimental and analytical representations of components into a complex nonconservative system model where the goal is to predict the load field on the various components due to known inputs to the system is presented. Static correction terms are used to improve the modal representation of components by accounting for the effect of truncated higher frequency modes. Loads, stresses, and strains as experienced by individual components can be determined with a high degree of confidence. These strain time histories can then be used for fatigue life prediction of the components. The process is illustrated with an example involving durability studies of a military vehicle design.

86-2290
Natural Vibration Characterization as a Tool for Analysing and Preventing the Failures of Components in Service — A Few Case Studies
S.K. Bhave, S.K. Goyal
Bharat Heavy Electricals Limited, Hyderabad, India
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 233-237, 1 fig, 1 table, 1 ref

KEY WORDS: Experimental modal analysis, Case histories, Fatigue life, Stress amplification factors, Turbine components

Modal analysis techniques can be very effectively used in analyzing in service fatigue failures. It has been shown that in addition to vibration testing, it is advantageous to measure the dynamic strains and consequent stress amplification factors during sine sweep tests since this enables one to immediately judge the damage potential of a given resonant frequency. This further enables structural engineers to identify those frequencies which are harmful and to implement appropriate corrective action. Three case studies are presented where modal analysis techniques were successfully used in analyzing and correcting the in-service failures of components.

86-2291
Mechanics of Fatigue Damage and Degradation in Random Short-Fiber Composites, Part I — Damage Evolution and Accumulation
S.S. Wang, E.S.-M. Chim, H. Suemasu
J. Appl. Mech., Trans. ASME, 53 (2), pp 339-346 (June 1986) 17 figs, 21 refs

KEY WORDS: Fatigue life, Fiber composites

Cyclic fatigue damage in random short-fiber composites is studied experimentally and analytically. In the experimental phase of the study, the fatigue damage is observed to involve various forms of microcracking, originated from microscopic stress concentrators in the highly heterogeneous microstructure. In the analytical portion of the study, a probabilistic treatment of the microcracks is conducted to evaluate the statistical nature of the microscopic fatigue damage. Fatigue damage evolution and accumulation in the random short-fiber composite are analyzed in detail through the development of probabilistic microcrack density and distribution functions during the cyclic loading history.

86-2292
Elastic Wave Scattering from an Interface Crack in a Layered Half Space Submerged in Water: Part I: Applied Tractions at the Liquid-Solid Interface
S.M. Gracewski, D.B. Bogy
Univ. of Rochester, Rochester, NY
J. Appl. Mech., Trans. ASME, 53 (2), pp 326-332 (June 1986) 4 figs, 1 table, 8 refs

KEY WORDS: Submerged structures, Discontinuity-containing media, Elastic waves, Wave scattering

The analytical solution of time harmonic elastic wave scattering by an interface crack in a layered half space submerged in water is presented. The solution of the problem leads to a set of coupled singular integral equations for the jump in displacements across the crack. The kernels of these integrals are represented in terms of the Green's functions for the structure without a crack. Analysis of the integral equations yields the form of the singularities of the unknown functions at the crack tip. These singularities are taken into account to arrive at an algebraic approximation for the integral equations that can then be solved numerically. Numerical results in the form of crack tip stress intensity factors are presented for the cases in which the incident disturbance is a harmonic uniform normal or shearing traction applied at the liquid-solid interface. These results are compared with a previously published solution for this problem in the absence of the liquid.

ELASTICITY AND PLASTICITY

86-2293
Simplified Dynamical Analysis of Inelastic Structures
J. Zarka, P.K. Navidi
Ecole Polytechnique, Cedex, France
Nucl. Engrg. Des., 92 (1), pp 89-103 (Mar 1986) 13 figs, 3 tables, 16 refs

KEY WORDS: Elastic-plastic properties, Inertial forces

The behavior of structures made of elastic-plastic materials and subjected to quasi-static loadings is considered. A new simplified method is proposed for cases in which loadings are dynamic, i.e. when inertial forces cannot be neglected as seismic loads. The concepts are illustrated with elementary examples, and a general description of the method is given with more complex examples.

86-2294
On the Impact of a Rigid Sphere on a Viscoelastic Half-Space
N. Aksel
Universitat Karlsruhe, Karlsruhe, Fed. Rep. Germany
Ingenieur-Archiv, 56 (1), pp 30-54 (1986) 6 figs, 16 refs

KEY WORDS: Spheres, Impact response, Half-space, Viscoelastic properties

The impact of a rigid sphere on a viscoelastic half-space is studied. The viscoelasticity is assumed to be weak and the problem is solved by a perturbation technique with the classical Hertzian solution as the zeroth order approximation. The deformation process consisting of the approach and the restitution period is analyzed neglecting the wave effects. Simple expressions for the contact force and the penetration depth are obtained in analytically closed forms. The unknown time-path dependence is determined by applying Newton's Second Law to the rigid sphere. Simple expressions for the final penetration depth at the end of the contact are given and formulae for the coefficient of restitution are derived.

WAVE PROPAGATION

86-2295
Elastic Wave Scattering from an Interface Crack in a Layered Half Space Submerged in Water: Part II: Incident Plane Waves and Bounded Beams
S.M. Gracewski, D.B. Bogy
Univ. of Rochester, Rochester, NY
J. Appl. Mech., Trans. ASME, 53 (2), pp 333-338 (June 1986) 7 figs, 3 refs

KEY WORDS: Submerged structures, Discontinuity-containing media, Elastic waves, Wave scattering

This is Part II of a two-part paper which analyzes time harmonic elastic wave scattering by an interface crack in a layered half space submerged in water. The analytic solution was derived in Part I. Also numerical results for uniform harmonic normal or shear traction applied to the liquid-solid interface were presented. These were compared with previously published results as a check on the computer program used to obtain the numerical resuks. In Part II, additional numerical results are presented. Plane waves incident from the liquid onto the solid structure are first considered to gain insight into the response characteristics of the structure. The solution for an incident beam of Gaussian profile is then presented since this profile approximates the output of an ultrasonic transducer.

EXPERIMENTATION

MEASUREMENT AND ANALYSIS

86-2296
A Minimum Norm Perturbation Method for the Modification of Structural Analytic Model
De-Wen Zhang, Ling-Cheng Zhao
Beijing Institute of Structure and Environment Engineering, Beijing, China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 541-548, 2 tables, 4 refs

KEY WORDS: Modal analysis, Structural modification techniques, Perturbation theory

The basic concepts of the inverse perturbation method and optimization method are combined to formulate a minimum-norm perturbation method. The unknown numbers of the governing equations determining the perturbation stiffness and mass matrices are much greater than the numbers of the equations. To give a unique and reasonable solution to these indefinite matrix equations, formulae of perturbation matrix are derived based upon the minimum norm solution theory of linear algebra. In the calculation no trial-error and iteration processes are involved. The perturbation matrix pair can be obtained directly by algebraic manipulations.

86-2297
A Modal Synthesis Method for Multi-substructure Systems
Weiji Wang, Shijing Zhu
Nanjing Aeronautical Institute, China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 354-359, 5 figs, 1 table, 11 refs

KEY WORDS: Modal synthesis, Substructuring methods

A multi-substructure modal synthesis method is developed for a multi-substructure system in which a central substructure is surrounded by many other smaller substructures. The method is easy to use, decreases computer capacity demand

and requires little in cost as well as time. It has been applied to the modal analysis of multi-blade-disk system models. The calculation results and the modal test data of these systems are listed for comparison.

86-2298
Invariant Theorem of Relative Sensitivity Summation and Higher Order Sensitivity Analysis Applied to Structural Modification
Peng Zemin, Song Jianwei
Tianjin Univ., Tianjin, China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 66-74, 5 tables, 9 refs

KEY WORDS: Structural modification techniques, Sensitivity analysis, Viscous damping, Modal analysis

This paper deals with the sensitivity of modal parameters of mechanical structures. The formulae for evaluating the sensitivity of complex frequency, natural frequency, modal damping ratio and complex mode of a structure system with general viscous damping have been developed. Extending the theory of sensitivity developed in electric network research to analyze mechanical structures, it has been found that the invariant theorem concerning the relative sensitivity sum remains constant for a mechanical structure system. The relationship of the relative sensitivity of natural frequency and energy distribution has been established also for a non-damping system. General formulae for calculating sensitivity of higher orders of mechanical structures with general viscous damping system have been achieved as well.

86-2299
Structural Modification: A Comparison of Techniques
R. Jones, K. Iberle
Hewlett-Packard, Everett, WA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 59-65, 8 figs, 2 tables, 1 ref

KEY WORDS: Structural modification techniques, Modal analysis, Frequency response function

Two approaches to the problem of predicting modal parameters for a modified structural model are described. The first method involves manipulation of a modal model derived from a set of measured frequency response functions. The second method uses the measured data directly to generate a modified set of FRF's from which a new modal model can be derived. The theoretical background for these techniques is presented, followed by a comparison of the predicted and measured results for a test structure.

86-2300
An Efficient Method of Determining Rotational Degrees of Freedom from Analytical and Experimental Modal Data
J.C. O'Callahan, P. Avitabile, I.-W. Lieu, R. Madden
Univ. of Lowell, Lowell, MA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 50-58, 3 figs, 6 tables, 9 refs

KEY WORDS: Structural modification techniques, Finite element technique, Rotational degrees of freedom, Modal analysis

Structural modification procedures using beam and plate finite elements require the rotational degrees-of-freedom for moment transfers between the structure and the elements. However, in general, measurements include only translational motions of the test structure; therefore, the required rotational data must be generated in some fashion from the translational information. Since the finite element method includes elements that can simulate both translational and rotational motions, a method is developed using a finite element model in conjunction with the measured translational data to approximate a combined modal database of rotational and translational degrees of freedom. This new efficient technique uses the modal matrix from the finite element model and the experimental model to form an expansion matrix for the estimation of all the system degrees of freedom. Measured translational data is used to develop rotational along with additional unmeasured translational degrees-of-freedom. The method is illustrated for a simple structure.

86-2301
Method for Modifying Structural Dynamic Model by Means of Incomplete Complex Modes Identified from Experimental Data
Huang Liping, Chen Kecheng, Xu Zhandi
Beijing Institute of Aero. & Astro., Beijing, China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 434-438, 2 figs, 3 tables, 8 refs

KEY WORDS: Modal analysis, Structural modification techniques, Optimization, Penalty technique

A method based on the penalty function optimization technique is presented for modifying the structural dynamic model using incomplete complex modal parameters identified from the experimental data. It is suitable for the complex structures with nonproportional damping. Computer simulation and the example of a drill press show the validity of the proposed method for engineering problems.

86-2302
Design Sensitivity Analysis of Vibration Modes by Finite Element Perturbation
Su-huan Chen, H.H. Pan
Polytechnic Institute of New York, Brooklyn, NY
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 38-43, 2 figs, 1 table, 5 refs

KEY WORDS: Modal analysis, Design sensitivity analysis, Finite element technique, Perturbation theory

A very efficient finite element perturbation method is developed for the design sensitivity analysis of eigenvalues and eigenvectors in the vibration of a complex structure. Application of this method is illustrated by an example.

86-2303
The Application of the Time Domain Method in Strain Modal Analysis
T.-X. Song, P.Q. Zhang, W.Q. Feng, T.C. Huang
Univ. of Wisconsin, Madison, WI
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 31-37, 5 figs, 4 tables, 5 refs

KEY WORDS: Modal analysis, Strains, Time domain methods

The advantages of using strain signals as input data for strain modal analysis in the time domain are described. As an illustration, the damped natural frequencies and corresponding strain mode shapes are obtained from two experiments, one for a circular cylindrical tube and the other for a beam, by using the time domain method with strain measurement data. Both experimental results coincide well with the analytical results.

86-2304
Time Domain Modal Analysis of Random Vibrations
T. Fang, Zhen-ni Wang
Duke Univ., Durham, NC
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 270-275, 6 refs

KEY WORDS: Modal analysis, Random vibrations, Time domain method, Nonlinear systems, Statistical linearization

A time domain modal analysis for random responses of damped linear systems is developed. After uncoupling the system by a real or complex modal transform, the correlation function matrix of the modal response to white noise excitation is found directly in analytical form. The original system response is obtained by the modal transform. By properly enlarging the original system, the stationary response to filtered white noise excitation also can be found. Combined with the statistical linearization technique, these results are also useful in solving certain nonlinear random vibration problems.

86-2305
Improvement of Analytical Models with Input/Output Measurements Contra Experimental Modal Analysis
H.G. Natke
Universität Hannover, Fed. Rep. Germany
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 409-413, 3 figs, 12 refs

KEY WORDS: Experimental modal analysis, Phase resonance method, Phase separation method

Experimental modal analysis uses two principles in determining its results --phase resonance and phase separation. Phase resonance is based on appropriated excitations and uses estimation procedures only in a secondary way (single degree-of-freedom method); the phase separation technique needs input/output measurements caused by suitable excitation, and from the very beginning it applies estimation procedures. The results based on the first method are modal quantities often highly biased due to non-appropriate excitation. The results of the second method are estimated modal quantities with the known estimates of the covariances. The input/output measurements which are used in the phase separation technique can also be taken in order to improve (by estimation) the parameters of the analytical model. The modal quantities can then be calculated from the improved analytical model. This procedure seems to have advantages over experimental modal analysis in those cases in which further calculations have to be performed with the estimates.

86-2306

Modal Estimation of Lumped Parameter Systems Using Vector Data Dependent System Models

S.M. Pandit, R. Helsel, H. Evensen
Michigan Technological Univ., Houghton, MI

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 414-421, 1 fig, 3 tables, 10 refs

KEY WORDS: Modal analysis, Lumped parameter method, Time domain method, Data dependent systems

The theoretical framework of the vector data dependent system (DDS) methodology is applied to the response data from a lumped parameter system. This methodology has been tested both experimentally and through simulation using ACSL. The vector DDS model determines the elements of the mass, stiffness and damping matrices within five decimal places for the simulated system, and within experimental error for the real system. The DDS methodology uses discrete time difference equations to formulate an autoregressive moving average vector (ARMAV) model from digitized acceleration data. The ARMAV models are formulated in a state space format by simultaneously measuring the acceleration of each degree-of-freedom which is of interest. It is shown that the modal parameters (natural frequencies and mode shapes) can be evaluated by analyzing the system's free vibration. The system parameters (mass, damping, and stiffness matrices) can be evaluated by analyzing the response to a single known sinusoidal forcing function.

86-2307

A Comparative Study of Identification of Modal Parameters by TDM Using Single- and Multi-Excitations

P.Q. Zhang, W.Q. Feng, T.C. Huang
Univ. of Wisconson, Madison, WI

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 453-464, 5 figs, 4 tables, 4 refs

KEY WORDS: Modal analysis, Time domain method, Multipoint excitation technique, Single point excitation technique, Data processing

Various cases of computer-simulated time domain response were constructed to simulate the real experimental response with high damping, close modes or repeated roots. The multi-excitation time domain method (METDM) was performed on all these computer-simulated responses. Around 500 simulated computations were done; 172 of them were chosen to show the significant power of the METDM in identification of modal parameters with high damping, close modes or repeated roots. It is clear that the technique of exciting multiply and processing all data simultaneously is much more powerful than the single excitation technique.

86-2308

Global Frequency & Damping Estimates from Frequency Response Measurements

M.H. Richardson
Structural Measurement Systems, Inc., San Jose, CA

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 465-470, 10 figs, 5 refs

KEY WORDS: Mode shapes, Rational fraction polynomials, Curve fitting, Global fitting method, Natural frequencies

A new formulation of the rational fraction polynomial equations is presented which will obtain global estimates of modal frequency and damping from a set of frequency response functions (FRF) measurements. This algorithm can then be used in conjunction with the previously described global residue algorithm to obtain frequency, damping, and mode shape parameters from a set of FRF measurements. Included are some examples of the use of global curve fitting, as well as a discussion of the advantages and disadvantages of local versus global versus poly-reference curve fitting. The problem of compensating for the effects of out-of-band modes is covered, and the unique way in which this new global method can handle these effects is illustrated.

86-2309

Modal and Structural Parameter Identification by Time Series Analysis Using Digital Filtering

Tang Xiujin, Yuan Jingxia, S.M. Wu
Dalian Institute of Technology, Dalian, China

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 494-500, 8 figs, 6 tables, 6 refs

KEY WORDS: Parameter identification technique, Modal analysis, Time series analysis method

A method using time series analysis for determining the modal parameters of a structure by random noise excitation through the autoregressive moving average vector (ARMAV) model is summarized. A unique method for identifying the joint parameters of a structure is proposed. A digital filtering technique is proposed to reduce the adequate order of the ARMAV model. Two

examples are illustrated using the digital filtering technique for identifying the modal and structural parameters of the system.

86-2310
A Contribution to Structural Dynamics by Means of One Dimensional Elastic Waves
A. Mioduchowski, M.G. Faulkner
Univ. of Alberta, Edmonton, Alberta, Canada
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 536-540, 5 figs, 4 refs

KEY WORDS: Mode shapes, Elastic waves, Wave propagation

One dimensional wave propagation theory is used to investigate the forces, velocities and displacements in structures consisting of a series of elastic rods connected to rigid elements. The method is applied to the case of multimass drive systems (torsional waves), colliding subsystems (longitudinal waves) or multistoried buildings (shear waves). The problem is reduced to a system of ordinary differential equations with shifted arguments which must be solved in a certain sequence. A simple, effective and stable numerical procedure is proposed for solving the system of equations and some numerical results are presented.

86-2311
Experimental Modal Analysis with Stepped-Sine Excitation
H. Van der Auweraer, P. Sas, P. Vanherck, R. Snoeys
Kath. Univ. Leuven, Leuven, Belgium
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 572-580, 5 figs, 26 refs

KEY WORDS: Experimental modal analysis, Stepped-sine excitation

Due to the development of several new dynamic analysis methods which use experimental modal analysis results as input data, those results are subjected to more stringent accuracy demands. One of the techniques to achieve this goal is the use of stepped sine excitation. Although the principle of this technique is long known, a feasible implementation, suited for testing large structures or nonlinear systems, was only possible, making full use of today's possibilities in digital signal processing. The characteristics of the method are briefly reviewed, for single input as well as for multiple input testing. An implementation with response adaptive definition of excitation frequency and amplitude is presented and illustrated with some examples. The impact of this method on the estimation of the modal parameters is also discussed.

86-2312
Multiple Input Modal Analysis of Frequency Response Functions Based on Direct Parameter Identification
F. Lembregts, J. Leuridan, L. Zhang, H. Kanda
Kath. Univ. Leuven, Leuven, Belgium
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 589-598, 6 figs, 17 refs

KEY WORDS: Parameter identification technique, Mode shapes, Frequency response functions

A direct parameter identification (DPI) method is presented for modal analysis. Frequency response functions relative to several input stations are used simultaneously to extract global eigenfrequencies, damping values, mode shapes, and modal participation factors. This DPI method is based on a frequency domain second order linear model. An experimental test case shows the abilities of the method to handle noisy data on a highly damped structure with four modes.

86-2313
A Superelement Approach to Test-Analysis Model Development
D.C. Kammer, C.C. Flanigan, W. Dreyer
SDRC, Inc., San Diego, CA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 663-673, 2 figs, 10 tables, 8 refs

KEY WORDS: Experimental modal analysis, Spacecraft, Test models, Finite element technique

A systematic method is presented for developing test-analysis models (TAM) which can he used with modal survey test data to update and correct analytical loads analysis models. The method utilizes superelement capability developed for component mode synthesis to generate and correlate the TAM representation at the component level before proceeding immediately with the larger and more expensive system level TAM analysis. This approach greatly reduces the time and effort required while maximizing the understanding of the analytical model system dynamics.

86-2314
Modal Analysis for a Pneumatic Loader Mechanism
F.R. Gomaa, A. El Khatib, A. Nasser

Menoufia Univ., Egypt
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 802-811, 13 figs, 1 table, 13 refs

KEY WORDS: Modal analysis, Natural frequencies, Mode shapes

The effect of using pneumatic control on a loader mechanism -- modal shape and modal frequencies -- is investigated.

86-2315
Spectral Analysis of a Randomly Excited Duffing System
M. Yar, J.K. Hammond
Univ. of Southampton, Southampton, England
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 736-742, 4 figs, 1 table, 4 refs

KEY WORDS: Modal analysis, Spectrum analysis, Duffing oscillators

The second order Duffing system with cubic restoring force under Gaussian white noise excitation is considered. The evaluation of such a system is governed by its transion probability density function which is the solution of the Fokker Planck Kolmogorov (FPK) equation. The FPK equation associated with this system cannot be solved exactly. A variational approach is employed to obtain an approximate solution to the FPK equation. Using this approximate solution analytical expressions (approximate) for autocovariance and spectral density function are developed. The theoretical results are compared with digital simulation results. In the course of development the relationship between the solution of the FPK equation and modal analysis is noted.

86-2316
The Ensemble Variance of Random Noise in a Reverberation Room
J.L. Davy
Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia
J. Sound Vib., 107 (3), pp 361-373 (1986) 3 tables, 7 refs

KEY WORDS: Reverberation chambers, Sound measurement

The literature contains conflicting results for the ensemble relative variance of the intensity of a frequency band of random noise which has been passed through a reverberation room. Some theoretical and experimental results show that the ensemble relative variance is doubled. This paper shows that the magnitude of the effect depends on the ratio of the integrating time of the detector to the integrating time of the reverberation room. If this ratio is small the reverberation room has no effect. If the ratio is large the ensemble relative variance is doubled. This explains why conflicting results have appeared in the literature.

86-2317
Uses of Rigid Body Calculations in Test
J. Crowley, D.L. Brown, G.T. Rocklin
Structural Dynamics Research Corp., Milford, OH
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 487-493, 8 figs, 3 tables, 9 refs

KEY WORDS: Modal analysis, Data processing, Rigid body modes, Error analysis

The uses of forcing rigid body constraints to a test based modal model are discussed. By forcing an estimated rigid body mode to conform to a prescribed set of motions, sources of measurement efforts can be detected. These errors may be due to incorrect calibration, orientation, or position of the transducer. Another use of rigid body calculations is to force components which should exhibit rigid body characteristics over a certain frequency to be rigid. For example, an engine in a vehicle should remain rigid for the lower flexural modes of the vehicle. Due to measurement and curvefitting errors, the estimated mode shapes may not reflect this characteristic. The importance of rotational degrees-of-freedom when predicting structural modifications is also discussed and a method of determining these characteristics by assuming rigid body motion of a group of points is described.

86-2318
A Method of Determining the Modal Frequencies of Structures with Couple Modes
O. Dossing
Bruel & Kjaer, Denmark
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 478-486, 9 figs, 2 tables, 4 refs

KEY WORDS: Modal analysis, Deconvolution technique, Coupled response, Natural frequencies, Data processing

The free vibration of a single degree-of-freedom system following an excitation with an impulse,

can be regarded as a sinusoidal oscillation at the damped natural frequency multiplied, or weighted, by an exponential decay function. The spectrum can be viewed as a sine spectrum convolved with the transform of the exponential function. For systems with multiple degrees-of-freedom this convolution leads to smearing and modal coupling. The coupling effect can be significantly reduced by deconvolution of a measured frequency response. The deconvolution is obtained by weighting the response signal from an impact excitation or a measured impulse response. The transform of the weighted function is called the mode spectrum and is a line spectrum where each line represents a damped natural frequency. This paper presents the theory of the deconvolution together with experimental results from analytical data and from measurements made on a real structure with coupled modes.

86-2319
ZMODAL: A New Modal Identification Technique
F. Leonard
Institut de recherche d'Hydro-Quebec, Varennes, Quebec, Canada
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 471-477, 5 figs, 2 tables, 12 refs

KEY WORDS: Modal analysis, Parameter identification technique, Data processing, Ibrahim time domain technique

The Z-plane modal analysis (ZMODAL) algorithm is based on topological characteristics of amplitude and phase in Z-plane of the Z-transform of damped sinusoids. Since damping is a dimension of the signal representation space, it is possible to dissociate frequency modes that are close but have different damping coefficient. The algorithm is a trade-off between optimum utilization of information and CPU time. ZMODAL is particularly suitable for high modal densities and populations, and appreciable record lengths. It is based on free decay responses and does not call for force inputs. It accepts high-side-lobe-rejection spectral windows, which increase cross-modal rejection thus ensuring excellent results. A description of the appropriate domain of utilization of these spectral windows is included and a new method for quantitative evaluation of real mode-shape accuracy based on the phase output is proposed.

86-2320
Automated Methods of Frequency Response Function Quality Evaluation
R.G. Smiley, G.B. Patrick, R.C. Sohaney
Entek Scientific Corp., Cincinnati, OH
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 107-112, 5 figs, 1 table, 3 refs

KEY WORDS: Modal analysis, Data processing, Frequency response function

During experimental structural analysis projects, much of the difficulty encountered when experimental modal data is used in analytical studies arises from application of techniques designed to smooth over or average out errors in measured data. Some of these errors are traceable to structural effects such as local nonlinearities, which are difficult to work around. However, more often errors are the result of operator inexperience or lack of attention to detail during data acquisition. The resulting procedural errors can be broadly classified into two types -- systematic (present in all measurements) and random (only present in a few measurements). Results of the application of new, automated methods aimed at reducing the systematic errors common to measurements of frequency response functions are outlined. The coherence function's uses and short comings are also discussed.

86-2321
Time Shift Frequency Domain (TSFD) Modal Analysis
F. Leonard
Institut de recherche d'Hydro-Quebec, Varennes, Quebec, Canada
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 113-118, 6 figs, 1 table, 6 refs

KEY WORDS: Modal analysis, Data processing, Time shift frequency domain, Parameter identification technique

Time shift frequency domain (TSFD) modal analysis is a new identification technique giving the frequency, damping and mode shape from free-decay responses. It is assumed that the signal is composed of damped sinusoids and white noise. Since the main-lobe energy is associated with one sinusoid in the frequency domain, it is a function of the record length and time delay. If a delay is introduced between two Fast Fourier Transforms (FFTs) of the same signal, a relation is found to exist between the energy decay, the damping and the delay; this relation is used by the TSFD algorithm to evaluate modal damping. High cross-modal rejection (more than 90 dB) is then obtained with high side-lobe-rejection spectral windows. The TSFD algorithm, like the Ibrahim time domain analysis

and Z-plane modal analysis (ZMODAL) algorithms, does not require force inputs.

86-2322
Generating Modal Parameters that Compensate for Residual Energy
B.A. Brinkman
Structural Measurement Systems, Inc., San Jose, CA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 119-122, 7 figs, 2 refs

KEY WORDS: Modal analysis, Parameter identification technique, Curve fitting, Data processing

Most real structures have many more modes of vibration than is practical to include in a modal model. Therefore, most analyses are done with a truncated set of modal data. Lumping out-of-band modes into mass and flexibility terms has proved effective in parameter estimation techniques for improving the estimate of the in-band modal parameters. However, the residual terms themselves are unsuitable for inclusion in the modal model and are discarded. The use of additional modal parameters in parameter estimation (curve fitting) that compensate for the residual effects of out-of-band modes and thus improve the modal model is explored.

86-2323
Truncation and Time Delay Bias Spectral Estimation Errors in Structural Testing
M.W. Trethewey
Pennsylvania State Univ., University Park, PA
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 123-129, 6 figs, 14 refs

KEY WORDS: Experimental modal analysis, Data processing, Error analysis

When frequency response functions are estimated from finite time samples and Fast Fourier Transform algorithms, the estimated functions are subject to both random and bias errors. Three different bias errors encountered in typical dynamic structural tests are investigated. The time delay introduced by acoustic propagation causes a bias error, which is shown to be dependent on the capture window utilized. The magnitude of these bias errors is investigated and guidelines developed to minimize their effect. A series of experiments are performed to verify the developed relationships and demonstrate the bias error effects in typical structural dynamics testing situations.

86-2324
Contrasts in Two Classes of Structural Dynamic Correlation Procedures
I.U. Ojalvo
Univ. of Bridgeport, Bridgeport, CT
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 81-87, 4 figs, 5 refs

KEY WORDS: Correlation techniques, Parameter identification technique, Modal analysis, Linking analysis and test

Two classes of iterative analysis/test correlation procedures for structural dynamics have emerged over the past decade. The techniques employed in the first group, termed parameter identification, modify numerical input data, but never correct a faulty model when fundamental modeling errors exist. However, methods contained in the second group of iterative procedures attend to such problems through determination of physical locations at which problematic structural idealizations exist. Unfortunately, these latter procedures do not inform the user regarding how to improve the model, but rather serve as diagnostic tools. This paper reviews the basic problems associated with each group and shows how they differ and complement one another. Some generalizations, based upon numerical studies, are also offered regarding the application of parameter identification methods.

86-2325
An Exact Integration Algorithm for Use with Modal Analysis
R. Rodeman
Sandia National Labs., Albuquerque, NM
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 311-315, 4 figs, 2 refs

KEY WORDS: Linking analysis and test, Modal analysis, Frequency domain method, Integration methods

A modal analysis integration algorithm which is exact for a piecewise-linear excitation has been developed. Since, virtually all field excitations are represented in digitized form; a piecewise-linear representation is appropriate. The integration algorithm is obtained by constructing a recursive, ramp-invariant digital filter. The recursive form is simple; only five additions and five multiplications are necessary to determine a new response point. This algorithm is compared with the Newmark-beta, central difference, trapezoidal rule, and linear-acceleration algorithms. It is shown that the new algorithm has a

marked superiority. It is also shown that the classical algorithms can produce poor results, even when the algorithms are unconditionally stable.

86-2326
Model Optimization with Measured Modal Data by Mass and Stiffener Changes
W. Heylen
Kath. Univ. Leuven, Leuven, Belgium
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 94-100, 3 figs, 11 tables, 5 refs

KEY WORDS: Experimental modal analysis, Linking analysis and test, Mass matrices, Stiffness matrices

Model matrix optimization techniques use experimentally obtained modal characteristics to improve an existing mass and stiffness matrix model of the structure to yield a better agreement between analytical and experimental modal characteristics. The resulting model should present a far more reliable base for further (mathematical) applications of experimentally obtained modal data. An iterative method is described based upon the orthogonality conditions of the mode shape vectors with respect to the mass and stiffness matrix and the sensitivities of the resonant frequencies to mass and stiffness changes. Those stiffness changes are described as a removal, an addition or a modification of stiffeners. Since stiffeners take into account all six degrees of freedom in each point simultaneously, this technique allows an improved description of the torsional effects of stiffness changes.

86-2327
Modal Analysis Measurement Techniques Improve Response Measurements
J.B. Poland, R.W. Lally
Univ. of Cincinnati, Cincinnati, OH
Test, 48 (3), pp 10-13 (June/July 1986) 6 figs

KEY WORDS: Experimental modal analysis, Accelerometers

A response transducer system has been created which solves many problems encountered during modal data acquisition. Possibly the most common problem faced by the experimental engineer is obtaining enough time to perform the testing. This accelerometer system is inexpensive, which permits the test engineer to acquire more data channels simultaneously for less money, thus reducing the testing time. Additionally, these accelerometers are very lightweight, which means the addition of a large number of channels to the test structure will not change the structure's mass characteristics. Incorporated into the system are many procedures which allow the engineer to manage multiple channels of instrumentation without expending large amounts of time.

86-2328
The Laser Vibrometer: A Portable Instrument
C.J.D. Pickering, N.A. Halliwell, T.H. Wilmshurst
J. Sound Vib., 107 (3), pp 471-485 (June 22, 1986) 11 figs, 12 refs

KEY WORDS: Vibrometer, Lasers

A portable laser vibrometer is described which allows the engineer to simply point a laser beam at a target surface in order to obtain a measure of its vibrational velocity level in amplitude and phase. This noncontacting transducer will complement the accelerometer in situations where use of the latter is precluded; i.e., hot, light or rotating surfaces. The instrument is compact, portable, robust, user friendly, inexpensive and is safe for general on-site use. An investigation of the mechanisms which determine the noise floor is presented and minimization procedures are defined. The first prototype constructed has a dynamic range of 60 dB and a frequency response of 20 kHz, which is adequate for general use.

86-2329
An Analysis of Doubly Rotated Quartz Resonators Utilizing Essentially Thickness Modes with Transverse Variation
D.S. Stevens, H.F. Tiersten
Rensselaer Polytechnic Institute, Troy, NY
J. Acoust. Soc. Amer., 79 (6), pp 1811-1826 (June 1986) 6 tables, 25 refs

KEY WORDS: Quartz crystals, Resonators

Closed-form asymptotic expressions for the frequency-wavenumber dispersion relations in doubly rotated quartz plates vibrating in the vicinity of the odd pure thickness frequencies are derived from the equations of linear piezoelectricity and the associated boundary conditions on the major surfaces. The usual assumptions of small piezoelectric coupling and small wavenumbers along the plate are made and it is supposed that the pure thickness frequencies are sufficiently different that one pure thickness wave is dominant at a time. In the treatment the mechanical displacement is decomposed along

the eigenvector triad of the pure thickness solution to facilitate the asymptotic analysis. The fact that the wavenumbers along the plate are restricted to be small significantly reduces the complexity of the equations without neglecting any transformed elastic constants. The resulting asymptotic dispersion equation enables the construction of a scalar differential equation describing the transverse behavior of essentially thickness modes of vibration in doubly rotated quartz plates. The scalar equation is applied in the analysis of both trapped energy resonators with rectangular electrodes and contoured crystal resonators using established procedures. In particular, calculations performed for the contoured SC cut and a number of other doubly rotated orientations are shown to be in excellent agreement with experiment.

86-2330
The Response of a Semi-Infinite Fiber to a Pulse Applied Asymmetrically to its End
L.O. Wilson
AT&T Bell Labs., Murray Hill, NJ
J. Acoust. Soc. Amer., 79 (6), pp 1798-1810 (June 1986) 10 figs, 15 refs

KEY WORDS: Fiberglass, Wave propagation, Pulse excitation, Normal mode method

A normal mode theory has been developed concerning wave propagation down a semi-infinite or finite elastic cylinder due to a time-dependent load applied at one or both ends. To test the practicality of applying this theory, a nontrivial model problem concerning the dynamic response of a glass fiber to a certain pulse applied at its end representing tensile fracture is studied. After considerable analytical effort, the expansion coefficients for the modes are computed. Calculations concerning displacements and strains of the dominant modes are presented. When necessary, additional asymptotic analyses are done. It is possible to obtain a comprehensive description of the fiber's response to the pulse. However, the effort required to apply the theory to a general problem is extensive. If the problem formulation admits considerable simplification of the expressions for the modal expansion coefficients, the theory is probably both elegant and meaningful.

DYNAMIC TESTS

86-2331
Vibration Tests Data on the Bumpy Road System
F.H. Lee
Cambridge Univ., England
Rept. No. CUED/D-SOILS/TR-170, 125 pp (1985) PB86-178092/GAR

KEY WORDS: Test facilities, Vibration tests, Experimental data, Seismic excitation

The data report consists of vibration data gathered in a series of tests comprising 75 earthquakes carried out on the bumpy road shaking table system at an operating centrifuge acceleration of 40 g. The bumpy road shaking table at the Cambridge University Geotechnical Centrifuge is a facility which can impart a lateral base shaking acceleration to a specially designed model container while the latter is in centrifugal flight. The objective of these tests is to improve on current understanding of the mechanics of the bumpy road shaker.

86-2332
For Easy Testing of Unwieldy Payloads, Use a Slip Table
J. Perkins
Mechanical Technology, Inc., Skaneateles, NY
Test, 48 (3), pp 22-25 (June/July 1986) 10 figs, 1 table

KEY WORDS: Test facilities, Shakers

When the test payloads are small, horizontal testing can be successfully done with a shaker alone. However, for large or heavy payloads, a slip table is required. Except for the user interested in only low-frequency testing, either an unrestrained or a hydrostatic-bearing/oil-film slip table is generally the best choice, because it has both a large load capacity and a wide test frequency range.

86-2333
More Shipping Environment Knowledge Makes the Electrohydraulic Vibrator an Industrial Standard
F.C. Bresk
Lansmont Corp., Pacific Grove, CA
Test, 48 (3), pp 16-19 (June/July 1986) 5 figs, 6 refs

KEY WORDS: Electrohydraulic shakers, Standards and codes

Electrohydraulic vibration systems have become an industrial standard because they meet the needs of this field so well. In so doing they have helped to improve product reliability due to reduction of shipping damage, reduce packaging costs by reducing the incidence of overpackaging where it is unnecessary, and bring new products

to market faster by eliminating the need for trial shipment of pilot production runs.

86-2334
Analysis of Non Linear Structure by Programmed Impact Testing and Higher Order Transfer Function
T. Chouychai
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 743-747, 8 figs, 3 refs

KEY WORDS: Experimental modal analysis, Impact tests, Computer-aided techniques

Impulse excitation with a special mechanical hammer actuated by an electronic programmer is presented. Proposed devices circumvent the defects of the hand actuated hammer and give isolated or repeated impulse force excitation with adjustable level and adjustable time delays between impulses. Attention is paid to a second order transfer function to analyze nonlinearities. We suggest the second order Hilbert transform whose numerical computation uses multidimensional inverse Fourier transform with correcting terms.

DIAGNOSTICS

86-2335
Damage Detection in Offshore Platforms Using Vibration Information
F. Shahrivar, J.G. Bouwkamp
Lockheed Missiles and Space Co., Sunnyvale, CA
J. Energy Resources Tech., Trans. ASME, 108 (2), pp 97-106 (June 1986) 8 figs, 7 tables, 15 refs

KEY WORDS: Diagnostic techniques, Off-shore structures, Drilling platforms, Failure detection

Damage detection based on changes in dynamic characteristics is considered for eight-legged k-braced steel offshore oil and gas production towers. Both experimental and analytical results are presented to improve damage detection capabilities. A 1/50th scale plastic model representing the structural system of a typical full-scale tower in 218 ft. (66m) of water is used for the studies. Effects of severance of diagonal bracing members on selected vibration frequencies and mode shape parameters measurable at the deck are investigated. The effects of changes in deck mass, increase in jacket mass, and deck mass eccentricity on the selected parameters are also investigated and are shown to be different from the effects of damage.

86-2336
Diagnostic Evaluation of Machinery Using Vibration Signature Analysis
J.E. Berry
Technical Assoc. of Charlotte, Inc., Charlotte, NC
S/V, Sound Vib., 20 (6), pp 10-17 (June 1986) 18 figs, 2 tables

KEY WORDS: Diagnostic techniques, Machine diagnostics, Vibration signatures, Signature analysis

This article provides vibration diagnostic evaluation case histories based on analyses on three distinctly unique machine types: a low speed calender roll having high impedance between the machine vibration sources and the transducer locations on the machine housing; medium speed vacuum pumps which demonstrate the necessity of generating and analyzing vibration signatures before diagnosing the machine to be in good operating condition; and high speed centrifugal compressors requiring specialized techniques and instrumentation in order to accurately evaluate and properly diagnose problems unique to these machines.

86-2337
A Modal Model for Fatigue Crack Non-Destructive Testing
M.D. AL-Ansary, K.M. Azayem
Kuwait Univ., Kuwait
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 202-208, 10 figs, 2 tables, 5 refs

KEY WORDS: Diagnostic techniques, Modal analysis, Shafts, Crack detection

The modal analysis technique is used as a nondestructive test to detect fatigue cracks in simple shaft-bearing systems. The method used is based upon the fact that the dynamic characteristics of a structure (such as the modal frequencies) change with the introduction of a crack. The inverse problem of estimating the crack size, location, and possibly geometry from the knowledge of the changes in the modal frequencies is discussed. The crack in the shaft is modeled as a torsional spring element because the crack introduces a discontinuity in the slope curve of the shaft. An analytical method and a finite element method are used to determine the modal frequencies variations for various crack sizes and locations on the shaft.

86-2338
Pipeline Leak Detection Using System Identification
Chen Meng Luo, H.R. Martin

Univ. of Waterloo, Waterloo, Ontario, Canada
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 624-628, 6 figs, 5 refs

KEY WORDS: Diagnostic techniques, Pipelines, System identification techniques

Of all the methods available for systems dynamics identification, only one is capable of being used during the normal operation of the system. This method uses an artificially created signal which consists of a series of pulses which have statistical properties identical to that of white noise, but are periodic in nature. This is termed pseudo random binary sequence (PRBS), and because of its periodicy, requires much shorter sampling times than true white noise to complete signal processing. This technique has been developed to detect leaks in hydraulic pipe lines, using a micro modal analyzer for signal processing. The theoretical basis of the method is described which makes use of the imaginary part of the pressure frequency response function. Some experimental results are also presented, taken from an oil hydraulic pipe line with a simulated leak. The test results show that this method is reasonably accurate, and has a significant potential as a general leak detection system for pipe lines.

86-2339
Illustration of the Use of Modal Assurance Criterion to Detect Structural Changes in an Orbiter Test Specimen
W.M. West
NASA Lyndon B. Johnson Space Ctr., Houston, TX
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 1-6, 4 figs, 3 tables, 4 refs

KEY WORDS: Experimental modal analysis, Failure detection, Spacecraft, Case histories

The modal assurance criterion provides a numerical basis for identifying changes in dynamic characteristics. The scalar constant is normally used to indicate consistency between modal vector estimates obtained from an empirically-based model and modal vector estimates obtained from a finite element model. Application of the modal assurance criterion to vector estimates, obtained at successive intervals in the operational life of a structure, provides a basis for determining that significant structural change has occurred. The basis for isolating the change, or damage, to a particular locale is also determined. This paper illustrates that application of numerical processes to modal test data, obtained at successive intervals in an environmental test of an Orbiter aft bulkhead provided an indication of change in dynamic characteristics caused by local fatigue damage and wear on friction producing seal surfaces.

BALANCING

86-2340
Multiplane Balancing Computer Program
M. Kovacevic
Nikola Tesla-B Power Plant, Belgrade, Yugoslavia
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 217-222, 2 figs, 3 refs

KEY WORDS: Multiplane balancing techniques, Rotors, Computer programs

The program can be used for field balancing rotors on various rotating machinery comprising arbitrary number n bearings and correcting planes. The complex influence numbers method is used. The gradual upper relaxation method is applied to solve n linear algebraic equations system representing a problem's mathematical model. Besides problem definition and algorithm description, a complete program listing as well as a detailed user guide is presented. The program is easily adaptable to most personal computers.

MONITORING

86-2341
Predictive Maintenance Programs for the Power Generation Industry
K.R. Piety, E.F. Pardue
Computational Systems Inc., Knoxville, TN
S/V, Sound Vib., 20 (6), pp 18-21 (June 1986) 3 figs, 1 table

KEY WORDS: Monitoring techniques, Power plants (facilities)

The advent of portable intelligent vibration data collection units integrated with a host computer executing comprehensive data management and analysis software has gained widespread attention within the utility industry. Predictive maintenance programs using this new generation of instrumentation can be implemented with significantly reduced manpower and capital dollar investment. A number of utilities have adopted predictive maintenance programs utilizing vibration analysis

as the prime indicator of machinery health. This represents a significant change within the power generation industry. This article specifically describes the experiences of five different utilities.

86-2342
Diagnosis of Fractures in Machinery
M. Kujath, Jiansen Li
Technical Univ. of Nova Scotia, Halifax, NS, Canada
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 611-616, 2 figs, 3 tables, 4 refs

KEY WORDS: Monitoring, Machine diagnostics, Fracture detection, Stiffness

Operation of machinery being monitored by the measurement of vibration signals is investigated to determine the presence and extent of fractures in the vibrating structure. Two different methods of detecting the fracture extent are presented. Both methods have been designed to utilize the displacement measurements alone, while the exciting forces remain unknown. The key concept incorporated in the procedures consists in observation and processing of transition vibrations which follow fracture. The developed procedures make use of system identification techniques which have been applied to equations describing different features of the processed vibration signals.

86-2343
Application of Kurtosis to Damage Mapping
E. Volker, H.R. Martin
Beta Con, Toronto, Ontario, Canada
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986 Vol. 1, pp 629-633, 9 figs, 4 refs

KEY WORDS: Monitoring techniques, Bearings

The traditional method of monitoring the condition of moving surfaces; i.e., bearings, is to study the trend of vibrational energy concentrated in different frequency bands as a function of machine life. An alternative approach is a figure of merit classification based on statistical assessment of vibrational data, called the Kurtosis method. The geometric surface irregularities which result from progressive damage to sliding surfaces, have distinct patterns, depending on the type of damage. Each pattern will produce a detectable signal from an accelerometer, which in turn, using FFT techniques, results in distinct spectral energy distributions. The results from combining Kurtosis measurements, with the traditional g vibration levels, to form a K-G damage map for each surface is discussed. It is shown that these maps can give a good insight into the damage process that is in progress, and to some extent predict when total failure can be expected to occur.

ANALYSIS AND DESIGN

ANALYTICAL METHODS

86-2344
A New Transfer Matrix Method for Response Analysis of Large Dynamic Systems
A.S. Kumar, T.S. Sankar
Concordia Univ., Montreal, Quebec, Canada
Computers Struc., 23 (4), pp 545-552 (1986) 3 tables, 10 refs

KEY WORDS: Transfer matrix method

A new transfer matrix method for the dynamic response analysis of large dynamic systems is proposed. This method, named as discrete time-transfer matrix method, is based on the conventional transfer matrix methods and the numerical solution procedures of differential equations. It combines the advantages of both of these methods. Formulation of the method as well as some numerical examples to check the viability of the method are given. Also identified are several possible areas of applications as well as the possible sources of errors.

86-2345
Dynamics of Multibody Systems with Variable Kinematic Structure
Y.A. Khulief, A.A. Shabana
Univ. of Illinois, Chicago, IL
J. Mech., Transm., Autom. in Des., Trans. ASME, 108 (2), pp 167-175 (June 1986) 7 figs, 2 tables, 17 refs

KEY WORDS: Multibody systems, Variable material properties, Finite element technique, Modal analysis

The problem of predicting the dynamic behavior of a general multibody system subject to kinematic structure changes is addressed using a mixed set of Lagrangian coordinates. Changes in the kinematic structure may occur smoothly or accompanied by a change in the system mo-

menta. The finite element method is employed to estimate the modal characteristics of flexible bodies. An automated pieced-interval computational scheme that accounts for the change in the dynamic characteristics due to the imposition of new sets of constraints on the boundaries of flexible components is developed. The resulting change in the deformation modes and the associated change in basis of the configuration space requires a new set of generalized coordinates for each subinterval of the analysis. A numerical example is used to demonstrate the analysis scheme developed in this paper.

86-2346

Design Derivatives of Eigenvalues and Eigenfunctions for Self-Adjoint Distributed Parameter Systems

R. Reiss
Howard Univ., Washington, D.C.
AIAA J., 24 (7), pp 1169-1172 (July 1986) 9 refs

KEY WORDS: Eigenvalue problems, Continuous parameter method

Analytic expressions are obtained for the design derivatives of eigenvalues and eigenfunctions of self-adjoint linear distributed parameter systems. Explicit treatment of boundary conditions is avoided by casting the eigenvalue equation into integral form. Results are expressed in terms of the linear operators defining the eigenvalue problem, and are therefore quite general. Sufficiency conditions appropriate to structural optimization of eigenvalues are obtained.

86-2347

Representation of System Response Using Expansions of Hermite and Beranek Functions

R.H. Lyon
Massachusetts Institute of Technology, Cambridge, MA
J. Acoust. Soc. Amer., 79 (6), pp 1850-1856 (June 1986) 6 figs, 12 refs

KEY WORDS: System analysis, Time domain method, Frequency domain method, Transfer functions

A new representation of system functions in the time and frequency domains using Hermite functions is introduced. The properties of such a representation are compared and contrasted with the well-known Laguerre expansion of system temporal response. It is argued that the Hermite functions are more relevant representations of systems with many degrees-of-freedom, and offer other mathematical and conceptual advantages as well. A new set of functions related to Hermite functions by the Hilbert transform are introduced, and are named Beranek functions. The use of these representations is illustrated by an application to the transfer function for a lossy acoustical pipe.

86-2348

A Theoretical and Experimental Investigation of Contact Loss in the Clearances of a Four-Bar Mechanism

M.T. Bengisu, T. Hidayetoglu, A. Akay
Wayne State Univ., Detroit, MI
J. Mech., Transm., Autom. in Des., 108 (2), pp 237-244 (June 1986) 13 figs, 2 tables, 28 refs

KEY WORDS: Multibody systems, Four bar mechanisms, Clearance effects

The dynamic behavior of a four-bar mechanism with a clearance of any one of its connections is described using a quasi-static model. Prediction of separation at the joints is based on the deviation of the model at these positions from the zero-clearance values. Corresponding experimental studies have verified the theoretical results. The existing criteria on the prediction of contact loss are discussed and a new criterion is offered.

86-2349

Selection of Initial Vectors for Subspace Iteration Method

T.C. Cheu, C.P. Johnson, R.R. Craig, Jr.
AVCO Corp., Stratford, CT
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 44-49, 7 tables, 12 refs

KEY WORDS: Subspace method, Iteration, Modal analysis

The effects of selecting initial vectors on computation efficiency for a subspace iteration method are investigated. Four algorithms are used for selecting the initial vectors. First, arbitrary starting iteration vectors are chosen according to Bathe and Wilson's algorithm. In the other algorithms, the initial vectors are the retrieved eigenvectors from Guyan and quadratic reduction methods. Improvement of the eigenvalue approximations of the subspace iteration method over reduction methods is presented. Computation effort is examined for the various algorithms used for initial iteration vectors.

86-2350

Free Vibration Analysis by BEM Using Particular Integrals

S. Ahmad, P.K. Banerjee

State Univ. of New York, Buffalo, NY
ASCE J. Engrg., Mech., 112 (7), pp 682-695 (July 1986) 3 figs, 4 tables, 16 refs

KEY WORDS: Boundary element technique, Particular integral method

A new method for the free-vibration analysis using the boundary element technique is presented. The method utilizes a fictitious vector function to approximate the inertia forces and then uses the well-known concept of complementary functions and particular integrals to solve the resulting governing differential equations. The necessary particular integrals are defined for the two and three-dimensional analyses, and the present formulation is applied to a number of two-dimensional problems to show its accuracy and efficiency in the solution of realistic engineering problems.

86-2351
A General and Efficient Method for Dynamic Analysis of Mechanical Systems Using Velocity Transformations
S.S. Kim, M.J. Vanderploeg
Univ. of Iowa, Iowa City, IA
J. Mech., Transm., Autom. in Des., Trans. ASME, 108 (2), pp 176-182 (June 1986) 5 figs, 2 tables, 24 refs

KEY WORDS: Multibody systems

A new formulation for the equations of motion of interconnected rigid bodies is presented. This formulation initially uses Cartesian coordinates to define the position of the system, the kinematic joints between bodies, and forcing functions on and between bodies. The equations of motion are then derived in terms of relative joint coordinates through the use of a velocity transformation matrix. The velocity transformation matrix relates relative coordinates to Cartesian coordinates. Use of both Cartesian and relative coordinates produces an efficient set of equations without loss of generality. The algorithm is implemented in a general purpose computer program using examples to demonstrate the generality and efficiency of the algorithms.

86-2352
QR Decomposition for State Space Representation of Constrained Mechanical Dynamic Systems
S.S. Kim, M.J. Vanderploeg
Univ. of Iowa, Iowa City, IA
J. Mech., Transm., Autom. in Des., Trans ASME, 108 (2), pp 183-188 (June 1986) 6 figs, 1 table, 25 refs

KEY WORDS: Multibody systems

A numerical solution method for dynamic analysis of constrained mechanical systems is presented which reduces a coupled set of differential and algebraic equations to state space form. The reduction uses an independent set of velocities which lie on the tangent plane of the constraint surface. The tangent plane is defined by the nullspace of constraint Jacobian matrix. An updating algorithm, used instead of repeated decomposition, preserves directional continuity of the Jacobian matrix and increases efficiency. State equations, derived in terms of independent accelerations, can efficiently be integrated and generalized velocities are integrated with constraints to obtain positions. This method has demonstrated minimal constraint violations and improved efficiency. Numerical examples with singular configurations and redundant constraints are presented to demonstrate the effectiveness of the method.

NONLINEAR ANALYSIS

86-2353
The Influence of an Internal Resonance on Non-Linear Structural Vibrations Under Two-Frequency Excitation
R.H. Plaut, N. HaQuang, D.T. Mook
Virginia Polytechnic Institute and State Univ., Blacksburg, VA
J. Sound Vib., 107 (2), pp 309-319 (June 8, 1986) 11 figs, 11 refs

KEY WORDS: Internal resonance, Nonlinear systems

A system of equations with quadratic and cubic nonlinearities is considered which models structural elements having initial curvature and exhibiting mid-surface stretching during motion. The excitation has two harmonic components. The results are obtained by the method of multiple scales and are presented as plots of modal amplitudes versus excitation amplitude, detuning of the combination resonance, and detuning of the internal resonance.

86-2354
Detection of Nonlinear Dynamic Behavior of Mechanical Structures
M. Mertens, H. Van der Auweraer, P. Vanherck, R. Snoeys
Kath. Univ. Leuven, Leuven, Belgium
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 712-719, 12 figs, 12 refs

KEY WORDS: Experimental modal analysis, Nonlinear systems

Nonlinear dynamic behavior of three types of mechanical structures is studied. The structures tested were a longitudinal beam of a car frame, a measuring instrument, and the IGLOO module of the ESA space lab. These structures show a significant degree of nonlinearity. Popular methods to check linearity are Maxwell's reciprocity theorem and the superposition principle, both rather cumbersome techniques. The directives to develop a more practical and reliable detection method are described.

86-2355
Nonlinear Analysis of Two-Link Pendulum with Application to Robot Manipulator
I.C. Chang
City Univ. of New York, Staten Island, NY
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 24-30, 4 figs, 10 refs

KEY WORDS: Modal analysis, Pendulums, Robots, Lagrange equations, Nonlinear theories

The problem of the nonlinear vibration of a double pendulum is investigated in order to model robot manipulator dynamics. The findings of this analysis may be applicable to robot control and design. The double pendulum system is presented by two plane oscillatory point-masses linked by weightless rods. Three cases are considered in which both rods are rigid, one rod is rigid and the other is elastic, and both rods are elastic. The Lagrangian equations are first formulated as a special case of a generalized gyroscopic system and then solved by using Poincare's small parameter method.

NUMERICAL METHODS

86-2356
A Hybrid Numerical Integration Method for Machine Dynamic Simulation
T.W. Park, E.J. Haug
Computer Aided Design Software Inc., Oakdale, IA
J. Mech., Transm., Autom. in Des., Trans. ASME, 108 (2), pp 211-216 (June 1986) 9 figs, 3 tables, 13 refs

KEY WORDS: Integration, Numerical methods, Machines, Simulation

An efficient and stable method for solving mixed-differential algebraic equations of constrained mechanical system dynamics is presented. The algorithm combines constraint stabilization and generalized coordinate partitioning methods, taking advantage of their attractive speed and error control characteristics, respectively. Three examples are studied to demonstrate efficiency and stability of the method.

STATISTICAL METHODS

86-2357
Response Statistics of Discretized Structures to Non-Stationary Random Excitation
C.W.S. To
Univ. of Calgary, Calgary, Alberta, Canada
J. Sound Vib., 105 (2), pp 217-231 (Mar 8, 1986) 6 figs, 2 tables, 7 refs

KEY WORDS: Statistical analysis, Random response, Displacement analysis, Velocity, Antennas

Closed-form time-dependent response statistics, discretized by the finite element methods and subjected to a wide class of nonstationary random excitations, are presented. The response statistics include the contribution due to the evolutionary coincident and quadrature spectral density functions. Application of the expressions obtained has been made to a quarter-scale physical model of a class of mast antenna structures excited at the base. Computed results indicate that the contribution due to the evolutionary quadrature spectral density function is insignificant.

PARAMETER IDENTIFICATION

86-2358
On the Parameter Identification of Elastomechanical Systems Using Weighted Input and Modal Residuals
N. Cottin, H.G. Natke
Universität Hannover, Hannover, Fed. Rep. Germany
Ingenieur-Archiv., 56 (2), pp 106-113 (1986) 3 tables, 7 refs

KEY WORDS: Parameter identification technique, Least squares method, Frequency domain method, Weighted residual technique

Parameter estimation by means of the method of least squares leads, in the case of linear elastomechanical systems, to nonlinear estimators if the output errors are used for the residuals, in which the measurement errors in general are assumed to be white noise. Linear estimators

can be obtained if use is made of generalized models, i.e., of generalized errors (equation errors). In this paper input errors and equation errors from the eigenvalue equation (according to the elastomechanical model) are taken for input residuals and modal residuals respectively, in order to obtain linear estimators in the frequency domain. Due to the correlation of these residuals, the resulting parameter estimates would be biased. However, bias and variance of the estimates can be considerably reduced if the least squares are weighted with appropriate weighting matrices which are statistically founded. Besides theoretical investigations with regard to this point, this statement is tested by means of a simulation study.

86-2359
Update and Identification of Dynamic Mathematical Models
B. Caesar
Dornier System GmbH, Friedrichshafen, Fed. Rep. Germany
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 394-401, 4 figs, 5 tables, 11 refs

KEY WORDS: Experimental modal analysis, Parameter identification technique

An overview on methods used for the generation of system matrices fitted to test results by updating and direct identification of dynamic mathematical models is presented. Comments on the applicability of these methods to real structures are given. Emphasis is on the discussion of direct update methods and possibilities to improve these methods.

86-2360
Direct Identification of Modal Parameters from the Steady-State or Free Response Data
Tang Renzhong, Tong Zhongfang, Cheng Yaodong, Sun Yueming
Zhejiang Univ., Zhejiang, China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 276-282, 2 figs, 3 tables, 5 refs

KEY WORDS: Modal analysis, Parameter identification technique, Time domain method, Periodic response, Random response

The paper presents a gram determinant discrimination method for the determination of the order and a multistage least-squares method for estimating the modal parameters of the vibration system from the steady-state response data or the free response data. Simulation studies are carried out for verification of the applicability of the method. The results of estimation are in close agreement with theoretical values.

86-2361
Time-Domain Identification of Vibration Parameters
Yao Yingxian
Nanjing Aeronautical Inst., China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 290-296, 1 fig, 2 tables, 6 refs

KEY WORDS: Modal analysis, Parameter identification technique, Time domain method, Z-transform

The theoretical background and procedure for identifying vibration parameters in the time domain from measured stationary responses are presented. These are applicable to a linear unsymmetrical multivariable vibratory system. The difference equation is a proper mathematical model for the time-domain identification of a sampled system and the sampled system is analyzed in detail in terms of a complex modal theory in the Z-transformation domain. The identification algorithm is described to improve the accuracy of the results.

86-2362
Single Mode Modal Identification of Insufficiently Separated Modes an Interference Criterion
J.M. Montalvao e Silva, N.M. Mendes Maia
Technical Univ. of Lisbon, Lisbon, Portugal
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 182-188, 7 figs, 2 tables, 4 refs

KEY WORDS: Modal analysis, Parameter identification technique

Single mode modal identification techniques are easily implemented in small microcomputers and provide the user with accurate results except in situations where resonances are insufficiently separated. Those situations are analyzed and a method is proposed to improve the accuracy of the estimates of the complex modal flexibilities. Some examples are presented to demonstrate the validity of the method.

86-2363
Modal Parameter Estimation from Base Excitation
J.-G. Beliveau, F.R. Vigneron, Y. Soucy, S. Draisey

Univ. of Vermont, Burlington, VT
J. Sound Vib., 107 (3), pp 435-449 (June 22, 1986) 7 figs, 5 tables, 8 refs

KEY WORDS: Parameter identification technique, Base excitation, Experimental modal analysis

Current software packages used for modal parameter identification are based on measured frequency response of either a fixed structure having no rigid body modes or a free structure with flexible supports. Procedures are now available to extract complex modes with the usual assumptions that the mass, stiffness and damping matrices are symmetric. In the case of base excitation, the equations of structural dynamics involve relative displacement with respect to the base, rather than with respect to the inertial frame in reference. Measurements, usually in the form of acceleration, are, however, for the total response. A procedure is outlined for obtaining modal information from total acceleration measurements for the case of base excitation using current software capabilities. The frequency response of the acceleration measurements must be modified algebraically before parameter estimation is performed. Once this is done, the modal testing procedure remains the same as for the other experimental setups.

86-2364
A Frequency-Time Domain Modal Parameter Identification Technique
Li Yue-feng
Nanjing Aeronautical Institute, China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 812-818, 3 figs, 2 tables, 6 refs

KEY WORDS: Parameter identification technique, Frequency response functions, Frequency domain method, Time domain method, Modal analysis

A modal parameter identification method based on measured frequency response functions (FRF) but analyzed with a time domain algorithm is presented in order to combine the advantages of both frequency and time domain identification techniques. With a suitable spectral window, a frequency response is cut out for the inverse Fourier transform (IFT) from which a free vibration response containing only one or few modal elements can be cut out for extracting corresponding complex frequencies and modal vectors with the Ibrahim time domain technique. Repeating this program, all complex modal parameters in the measured FRF can be identified.

86-2365
Structural Identification from Time Domain Simulations
K. Fyfe, J.U. Thoma, F. Ismail
Univ. of Waterloo, Waterloo, Ontario, Canada
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 641-645, 8 figs, 8 refs

KEY WORDS: Modal analysis, Parameter identification technique, Time domain method, Computer programs

Time domain simulation of dynamic and control systems can be carried out using commercially available packages such as TUTSIM and ACSL. Results of these packages are frequently time traces of the response of the system due to an exciting signal. While the results in this form can be very useful by themselves, it is often desired to extract some frequency spectrum information. This is especially important in the case of dynamic systems, where modal parameters give great insight into their behavior. This paper discusses the analysis of two lumped MDOF systems that have been modeled using bondgraphs and numerically simulated using TUTSIM. A frequency analysis and synthesis package called FANSY was then used to extract the modal parameters from the simulation results. These parameters agreed very well with those obtained from eigen-solutions.

86-2366
On the Complex Modes Identification of Arbitrary Systems Based on the Transfer Function
Lu You-fang, Liu Man, Wang Pin
Jilin Univ. of Technology, China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 549-555

KEY WORDS: Parameter identification technique, Modal analysis, Transfer functions

The complex modes expansion of the transfer function, suitable to arbitrary systems is presented. General formulations of the complex mode parameters identification for arbitrary systems is also presented.

86-2367
Modelling and Parameter Identification of Vibrating Systems in Dynamic Space
Mingtao Xu, R.L. Hutson
Chongqing Univ., Chongqing, China
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 422-426, 4 figs, 6 tables, 5 refs

KEY WORDS: Modal analysis, Parameter identification technique, Mathematical models

A mathematical model of a dynamic system is viewed as a manifold in a dynamic space. A dynamic space is a Euclidean space of dependent variables and their derivatives. A method is presented for developing a mathematical model from the dynamic space. A method of parameter identification is presented and a number of examples to illustrate the method are included.

86-2368
A Contribution to Identification of Vibratory Systems
G.W. Stachowiak
Univ. of Western Australia, Nedlands, Western Australia
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 1, pp 427-433, 2 figs, 6 refs

KEY WORDS: Mode shapes, System identification techniques

A procedure for designing the identification experiments of vibratory systems is presented. The problem of identification may be solved in two stages. In the first stage based on a simplified experiment, an appropriate mathematical model and optimal dimensionless functions together with optimal invariances of similarity are determined. Based on the parametric form of the dimensionless function, necessary conditions for establishing the physical model of the real object are developed. In the second stage the proper identification based on the constructed physical model can be performed. Two illustrative examples are given.

AUTHOR INDEX

CALENDAR

DECEMBER

7-12 ASME Winter Annual Meeting, Anaheim, CA (ASME, United Engrg. Center, 345 East 45th Street, New York, NY 10017)

8-12 ASA, Anaheim, CA (Joie P. Jones, Dept. Radiology Sciences, Univ. of California, Irvine, CA 92717)

9-11 ASA Fall Acoustical Show, Anaheim, CA (katherine Cane, ASA Show Manager, Amer. Inst. of Physics, 335 E 45th St., New York, NY 10017)

1987

JANUARY

12-15 AIAA 25th Aerospace Sciences Meeting, Reno, NV

FEBRUARY

24-28 SAE International Congress "Excellence in Engineering," Cobo Hall, Detroit, MI (SAE Engrg. Activities Div., 400 Commonwealth Drive, Warrendale, PA 15096)

MARCH

10-12 Power Plant Pumps Symposium [Electric Power Research Institute], New Orleans, LA (Electric Power Research Institute, 3412 Hillview Avenue, Palo, Alto, CA 94304)

6-9 56th International Modal Analysis Conference [Union College and Imperial College of Science], London, England (IMAC, Union College, Graduate and Continuing Studies, Wells House -- 1 Union Ave., Schenectady, NY 12308)

6-8 AIAA 28th Structures, Structural Dynamics and Materials Conference, Monterey, CA

9-10 AIAA Dynamics Specialist Conference, Monterey, CA

APRIL

13-16 IEEE Intl. Conf. on Acoustics, Speech, and Signal Processing, Dallas, TX

13-16 IUTAM Symp. on Advanced Boundary Element Methods, San Antonio, TX

28-30 1987 SAE Noise and Vibration Conference, Traverse City, Michigan (SAE, 400 Commonwealth Drive, Warrendale, PA 15086 (412) 776-4841)

MAY

3-8 33rd International Instrumentation Symposium [Aerospace Industries and Test Measurement Divisions, Instrument Society of America], Las Vegas, NV (33rd International Instrumentation Symposium, 738 W. Larigo Ave., Littleton, CO 80120)

11-15 ASA Spring Meeting, Indianapolis, IN

12-13 International Appliance Technical Conference, Columbus, OH

JUNE

8-10 AIAA 19th Fluid Dynamics, Plasma Dynamics and Laser Conference

8-10 Noise-Con 87, Pennsylvania State University (Conference Secretariat, NOISE-CON

87, The Graduate Program in Acoustics, Applied Science Building, University Park, PA 16802)

16-18 11th Annual Meeting [Vibration Institute], St. Louis, MO (Dr. Ronald L. Eshleman, Director, Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254)

29-2 AIIAA/SAE/ASME/ASEE 23rd Joint Propulsion Conference, San Diego, CA

AUGUST

31-2 Twentieth Midwestern Mechanics Conference (20th MMC), Purdue University, West Lafayette, IN (Professors Hamilton and Soedel, School of Mechanical Engineering, Purdue University, West Lafayette, IN 47907)

SEPTEMBER

27-30 Vibrations Conference and Other Technical Conferences, Boston, MA

NOVEMBER

15-19 ASME Winter Annual Meeting, New York, NY

16-20 ASA Fall Meeting, Miami, FL

CALENDAR ACRONYM DEFINITIONS AND ADDRESSES OF SOCIETY HEADQUARTERS

AHS American Helicopter Society
1325 18 St. N.W.
Washington, D.C. 20036

AIAA American Institute of Aeronautics and Astronautics
1633 Broadway
New York, NY 10019

ASA Acoustical Society of America
335 E. 45th St.
New York, NY 10017

ASCE American Society of Civil Engineers
United Engineering Center
345 E. 47th St.
New York, NY 10017

ASLE American Society of Lubrication Engineers
838 Busse Highway
Park Ridge, IL 60068

ASME American Society of Mechanical Engineers
United Engineering Center
345 E. 47th St.
New York, NY 10017

ASTM American Society for Testing and Materials
1916 Race St.
Philadelphia, PA 19103

ICF International Congress on Fracture
Tohoku University
Sendai, Japan

IEEE Institute of Electrical and Electronics Engineers
United Engineering Center
345 E. 47th St.
New York, NY 10017

IES Institute of Environmental Sciences
940 E. Northwest Highway
Mt. Prospect, IL 60056

IMechE Institution of Mechanical Engineers
1 Birdcage Walk, Westminster
London SW1, UK

IFToMM International Federation for Theory of Machines and Mechanisms
U.S. Council for TMM
c/o Univ. Mass., Dept. ME
Amherst, MA 01002

INCE Institute of Noise Control Engineering
P.O. Box 3206, Arlington Branch
Poughkeepsie, NY 12603

ISA Instrument Society of America
67 Alexander Dr.
Research Triangle Pk., NC 27709

SAE Society of Automotive Engineers
400 Commonwealth Dr.
Warrendale, PA 15096

SEM Society for Experimental Mechanics (formerly Society for Experimental Stress Analysis)
7 School Street
Bethel, CT 06801

SEE Society of Environmental Engineers
Owles Hall
Buntingford, Hertz.
SG9 9PL, England

SNAME Society of Naval Architects and Marine Engineers
74 Trinity Pl.
New York, NY 10006

SPE Society of Petroleum Engineers
6200 N. Central Expressway
Dallas, TX 75206

SVIC Shock and Vibration Information Center
Naval Research Laboratory
Code 5804
Washington, D.C. 20375-5000

U.S. GOVERNMENT PRINTING OFFICE·1986–181–588/40012